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LABOUR USE AND FARM PLANNING IN KENYA

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Summary

Labour-use relating to certain crops and stock was recorded in 1956/7 on demonstration holdings in Kenya. The data are used to associate the requirements and availabilities of labour relating to two farm plans. The plans are typical of many others devised by the Department of Agriculture for introduction into the Reserves as part of the plan to intensify African agriculture. From the point of view of labour organization, one of the two farm plans is shown to be unworkable without substantial modification. It is clearly important that the plans which the African cultivator is encouraged to adopt should be viable in all respects. Previously there appears to have been no testing of the labour needs of farm plans. The data and illustrations included aim to make this now possible.

BRITISH administration brought to Kenya law and order and a rapidly increasing African population. In time this meant a fall in the size of family holdings and, because of tenure arrangements, an increasing fragmentation of holdings. These circumstances inevitably gave rise to serious overcropping and depletion of soil resources. Not unnaturally, over the years, official policy has been marked by a sustained endeavour to grapple with the problem of soil erosion in the African areas.

It was considered that soil fertility could be maintained only by systems of mixed farming practising a suitable rotation. But rotational farming was feasible only on a holding comprising a compact unit. This raised the problem of reallocating countless strips of land, which for some time was considered insuperable. In the last few years, however, a movement of consolidation and enclosure of African lands has rapidly gained ground. Consolidation of itself increases the possibility of overcropping, consequently the administration has insisted that consolidated holdings practise sound farming. Farm plans have been devised, appropriate to different ecological zones, which increase cash income and at the same time maintain fertility. They are based on ley-farming principles and include one or more high-value cash crops, e.g. coffee, tea, pyrethrum, pineapples. In this development of African agriculture the planning of holdings plays an important part. Indeed, on the soundness of these plans depends much of the ultimate success of the consolidation movement.

When first devised farm plans take account of certain physical factors. For example, the area devoted to cash crops is related to a target income, the arable/ley ratio has regard to fertility and family subsistence needs, and so on. Except in a very rough sense, however, no attempt appears to have been made to relate the labour needs of farm plans to the labour available to work them. Some plans have been successfully carried through on demonstration farms with a controlled labour force, but labour needs relate only to these specific plans. In connexion with farm

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planning work, however, a knowledge of labour requirements relating to crops and stock seems essential. If, for instance, labour needs exceed the labour available a farm may prove unworkable unless modified. On the other hand, if labour requirements fall short of that available it may mean lost opportunities for increased income. To put it another way, ignorance of labour requirements where labour is almost the sole cost item makes its optimum economic use between alternative enterprises difficult to determine. However, the difficulties of procuring appropriate labour-use data are an understandable deterrent.

Labour Requirements for Crops and Stock on Smallholdings at Farm Institutes

Between June 1956 and October 1957 labour requirements relating to crops and stock were recorded on certain smallholdings located on African farm institutes[1]; the results are shown below. The institutes are run by the Department of Agriculture and the holdings are used mainly to instruct students in the ways of better farming methods as they apply to consolidated holdings practising mixed farming and cash-crop production. The recording period was one of somewhat higher-than-average rainfall, but to overcome this and several other difficulties recording should be carried out, ideally, over a number of years.

It is difficult to decide on what basis farm-labour requirements should be measured.[2] Should they relate to the able and energetic cultivator who makes a thorough job of his farm tasks, or to his indolent and less able neighbour who is persistently late in planting and weeding his crops? Or worse still, should stop watches be aimed at the 'average cultivator working under average conditions' in the Reserves? All three reflect different standards of farming and provide different amounts of effort. Three possible methods of recording labour are as follows:

(*a*) By observing and timing specially (or randomly) chosen individuals as they work on their own strips in the Reserve. This method, though laborious, savours of reality, but the fact of observation is likely to influence the efforts of the cultivator. As far as Kenya is concerned data of this kind, being related to fragmented holdings, are not likely to be applicable to labour usage on consolidated smallholdings.

(*b*) By operating a farm plan or system on a controlled holding with a controlled labour force as at Bukuru [1]. This, of course, associates labour needs with a plan, and not with individual crops and stock, and the data are relevant only to that particular plan.

(*c*) Recording labour spent on crops and stock over a long period but within the setting of a farm system. This seems particularly relevant to Kenya conditions. It may be that close supervision of the observed holdings makes for artificial conditions. But supervision is necessary if

[1] At Siriba, Kapsabet, Kisii, Kabianga, Wambugu, and Embu. All holdings are situated in 'high-rainfall, mixed-farming zones'. Five holdings at Siribi were recorded for 18 months, the remainder for a year. The inquiry was initiated by the writer, then agricultural economist in the Kenya Government.

[2] Largely because African labour is rarely associated with machinery, which induces a certain uniformity and speed of field operations.

reasonable standards of cultivation and husbandry, which is a basic aim of official policy, are to be achieved.

The data are given as simple averages in the following tables. The number of observations shown against each crop, etc., does not necessarily relate to all operations. This arises because recording sometimes started after planting or because of a crop failure, &c. The data are shown in man-hours rather than in the usual man-days. This is cumbersome but avoids the need to recalculate the figures where the length of an actual working day differs from that of an assumed man-day. It is regretted that the tables are burdened with numerous footnotes but to avoid misinterpretation these are necessary.

Table 1 shows the average labour time required to prepare a seed-bed by different methods according to whether (*a*) it follows an arable crop,

TABLE 1. *Seed-bed Preparations.*[a] *Average Labour Requirements per Acre*[b]

Method[c]	*Tractor, no break*	*Oxen*		*Tractor and Oxen*[d]		*Hand*	
		No break	*Break ley*	*No break*	*Break ley*	*No break*	*Break ley*[e]
No. .	16	22	10	6	7	9	8
Man-hours	15	38	93	8½(T) 14(O)	5(T) 77(O)	277	434

a. Includes ploughing and, where appropriate, disking and harrowing.
b. There was no significant difference between average labour needs for long- and short-rain seed-bed cultivations.
c. *No break* indicates preparations following a field crop.
Break ley indicates ploughing-in a grass ley and subsequent preparations.
d. The tractor and oxen can clearly be used in varying combinations. Those shown are the average of those observed.
e. Refers to rotated Napier (Elephant) grass and includes its cutting and uprooting as well as subsequent preparations.

or (*b*) it involves breaking a ley. No cases were observed of a grass ley being broken by hand, but only that of Napier grass. This is unfortunate because the use of tractors or oxen, even for turning-in pasture, is the exception rather than the rule in the Native areas. In this respect demonstration holdings could well be made to approximate more nearly to Reserve conditions. The effort required to turn-in Napier grass may damp the ardour of those enthusiasts who urge the use of this fodder for stall feeding, particularly when it enters the rotation. Indeed, it might be doubted whether the ordinary cultivator would be prepared to face this task each year.

Tables 2 and 3 relate to the labour needs of certain field and cash crops. It may be of interest to the reader to compare requirements for certain of these crops with earlier work done in Tanganyika [2, 3]. Only two of the holdings had coffee in full bearing, and picking data relate to these.[1] The picking rate of 5 lb. of cherry an hour is used in the

[1] The picking rate is lower for a less-than-full crop.

TABLE 2. *Average Labour Requirements per Acre Relating to Certain Field Crops*[a] *(man-hours)*

Crop	*No.*	*Plant*[b]	*Weed*	*Harvest*[c]	*Clearing trash*	*Thresh*[d]
Maize	17	35	155	95[e]	29	44
Sorghum	8	26	203	90	55	62
Millet	9	19[f] 98	47 213	179	60	70
Beans[g]	25	63	99	41	..	27
Pigeon peas[h]	6	13	..	62	39	..
Sweet potatoes	10	79	100	44[j] 115	33[k]	..
English potatoes	9	51	126	189	50[l] 27[m]	..
Oats (hay)	8	15	115	78[n] 34	..	..
Grass leys[p]	14	A. 19 B. 107 C. 143	50	..	..	..
Napier grass	4	138	198	(q)	..	..

a. Except where noted, all operations are done by hand labour.
b. All crops planted in rows except where otherwise noted.
c. Includes carting-off crop.
d. Includes shelling and winnowing where these operations are applicable.
e. Involves stooking and picking of cobs.
f. Seed broadcast. A much quicker operation but requires absolutely clean seed-bed. Note in next line more weeding can be done on crop sown in rows.
g. There was no significant difference between beans interplanted and a pure stand except that the former has no weeding time, this being allocated to the cover crop.
h. In all cases observed, interplanted in maize. The cover crop receives all weeding time.
j. Forty-four man-hours was the average time taken to clear vines and plough-out small crop of roots prior to grazing off by stock. It took 115 man-hours on average to hand-harvest about twenty bags of roots for later consumption.
k. Cutting and preparation of vines prior to planting.
l. Ridging by hand. By tractor 7½ hours.
m. Spraying by hand. By tractor 10 hours.
n. Includes cutting, turning and stacking, the first line by hand and the second by tractor. Note that seed was broadcast.
p. A. Refers to Rhodes or molasses grass sown as seed and interplanted in maize.
B. Refers to Kikuyu/star-grass ley, sown as splits and interplanted (or under-sown) in maize.
C. Refers to molasses grass sown as seed in rows, as a pure stand.
q. Cutting and carrying green fodder to stock. It appears more useful to express this task on an animal unit rather than an acreage basis being related to feeding rather than area requirements. Cf. Table 4.

following way: half an acre of coffee with an average yield of 5 cwt. parchment an acre: a cherry/parchment ratio of 6:1 gives 1,680 lb. cherry, i.e. 336 hours picking time.

Table 4 contains more novel information relating to dairy stock maintained entirely on the smallholdings. Two of the observed holdings maintained stall-fed cattle which, it appears, require substantial amounts of labour. This system of milk production has several advantages under peasant farming conditions particularly where population pressure is

TABLE 3. *Average Labour Requirements per Acre Relating to Certain Cash Crops*[a] *(man-hours)*

Crop	*No.*	*Plant*	*Weed*	*Harvest*	*Other*
Cassava	2	136	[b]	372[c]	..
Sugar Cane[d]	3	na	36	347	..
Bananas	4	80	[b]	..	27[e] 114
Pineapples	3	na	151	na	..
Pyrethrum	2	161	402	na	..
Rice[f]	..	192	60	120	36
Onions	1	na	131	131	..
Vegetables[g]	5	93	232	na	..

Crop	*No.*	*Mulch*[h]	*Weed*	*Prune*	*Spray*	*Manure*	*Harvest*
Coffee	7	234	576	58	234	162	[i]

a. All operations done by hand, and cover a full year except for onions and rice.
b. Couch grass was not completely eliminated before these crops were planted. Subsequent infestation therefore caused labour needs for weeding to be greater than normal. Actual average weeding times were: Cassava 171 hours and Bananas 415 hours. Normally each crop would require about 100 weeding hours annually an acre.
c. Includes peeling of roots.
d. The eradication of one crop was observed, requiring 708 man-hours.
e. Mulching. Twenty-seven hours refers to existing stand and 114 hours to the initial mulching of a new stand.
f. Taken from *Kenya Nile Basin Water Resources Survey*. Report by Sir A. Gibb and Partners. Refers to irrigated paddy. Planting includes transplanting and nursery preparations. Harvest includes threshing. Other refers to watering.
g. No information is available on the type of vegetables grown.
h. This operation includes cutting and carrying of Napier grass for mulch. The time taken for this task is expressed on the coffee and *not* on the Napier grass acreage.
i. Not satisfactory to express on a per-acre basis because yields have large effect on picking times. The average rate of picking was *5 lb. of cherry an hour*, at time of full crop. To relate this to parchment divide the cherry yield by six.

high and holdings small. The use of Napier grass (by zero-grazing, i.e. soilage) substantially increases stock-carrying capacity—over three beasts an acre! Well-managed Napier grass will give five cuts a year and up to 80 tons of green fodder an acre. It therefore economizes the use of land. All manure is retained, and in so far as manuring allows a more intensive arable system to be practised and yields to be increased, land is further economized. However, exclusive concern with the intensive use of land, even where this is the limiting factor, could result in the uneconomic use of other resources. For example, under certain conditions labour used in directions other than milk production (by stall-feeding) might well increase farm income. The merits of the various alternatives can be tested by comparative farm budgets.

Overhead labour required for general maintenance is high and has to be done whatever rotation is being practised. Maintenance tasks can, of course, be kept for slack times.

TABLE 4. *Average Labour Needs Relating to Dairy Stock, per Animal per Year*[a] *(man-hours)*

No.	*Milking*[b]	*No.*	*Maintenance*[c]	*No.*	*F.Y.M.*[d]	*No.*	*Cut-and-carry*[e] *Napier grass*
4	132	4	73	10	33	4	29
2	132	2	157	1	90	2	155

Average Miscellaneous Overhead Labour = 48 hours/acre/year.[f]

a. The first line relates to holdings on which cattle graze all the year but are usually housed at night for the making of manure. The second line relates to two holdings on which cows are permanently housed and stall-fed.
b. Relates to hand milking and covers the 'dry period'; it includes time taken to wash buckets and utensils. The cows involved yielded on average about 200 gallons a year plus suckling for a calf.
c. Includes watering stock, littering the 'boma', chopping fodder, and cleaning out milkshed.
d. Includes mucking out cattle 'boma' and the carting and spreading of manure, excluding the manuring of coffee.
e. First line. For night-feeding in 'boma' when necessary, and supplementary feeding in the field during dry season. Second line. Cows fed entirely on Napier grass and this refers solely to cutting and carrying it to 'boma'.
f. Covers the maintenance of homestead, buildings, fences, hedges, cutting grass on terraces, and so on.

Total Labour Needs on Two Recorded Holdings

When farming is based on manual labour, data relating to the labour needs of crops and stock are useful to check the economic efficiency of labour in its various alternative uses. Labour inputs and gross outputs of produce can be valued and net incomes derived. Alternatively, where there are no employment alternatives outside agriculture, relative labour efficiency can be expressed as a gross-value/labour-input ratio for various enterprises [4]. It is suggested above that a knowledge of labour requirements is essential if successful farm systems based on manual labour are to be devised. The viability of a system or plan will depend on several factors, for example, whether it achieves adequate nutrition for the family; or a politically acceptable cash income; whether the arable/ley ratio maintains fertility; and so on. If any one of these factors proves inadequate the viability of the plan may prove doubtful. But this is also true if the available labour is physically incapable of carrying through the whole plan.

It may be useful, in order to illustrate the value of labour information, to relate the above data to the labour needs of actual farm plans. Two examples follow:

The first example is taken from one of the recorded holdings. This holding comprises 3·46 acres and on it family labour is assumed to be able to carry out the farm plan shown below. The plan is applicable to conditions found in the Star/Kikuyu-grass zone in Nyanza Province (with 60–70 in. rainfall annually). Such an intensive use of a very small area suggests it to be of value in a heavily populated region where the average size of holding is likely to be small. Four milk cows are kept

permanently housed and stall-fed. No young stock are reared on the holding. The stock is fed almost exclusively from hand-cut, highly productive Napier grass 'leys' (with some roots) which, to maintain vigour, are rotated in the arable area every four years. An extra patch of permanent Napier grass is used for mulching coffee. The heavy stocking clearly requires a high-yielding fodder crop which in turn requires heavy manuring and good pasture management. The stall-feeding of stock is assumed to provide the necessary manure. It should be added that all tasks are done by hand, including the uprooting of rotational Napier grass. The arable area is made up of seven 'fields' each 0·25 acres in size making a total of 1·75 acres. It incorporates a 7-year rotation, 3 years in crops and 4 years under Napier grass. The cropping sequence is as follows:

	Long rains	*Short rains*
1st year . .	Napier grass (break)	Sweet potatoes
2nd year . .	Maize i/p beans	Beans
3rd year . .	Maize i/p beans	Beans
4th year . .	Maize i/p beans (i/p Napier grass)	Napier grass
5th year . .	Napier grass	Napier grass
6th year . .	Napier grass	Napier grass
7th year . .	Napier grass	Napier grass

i/p = interplanted.

In the course of each cropping year the arable area carries: 0·75 acres maize, 0·75 acres beans interplanted, 0·5 acres beans pure stand, 0·25 acres sweet potatoes, and 1·0 acre Napier grass. One acre of arable land is manured annually in addition to coffee and bananas. The remainder of the holding comprises: 0·37 acres bananas, 0·06 acres vegetables, 0·25 acres coffee, 0·53 acres sugar-cane, 0·21 acres additional Napier grass, 0·24 acres homestead and road. The small balance is accounted for by hedges, &c.

On the basis of average labour requirements given above, the running of this holding requires 4,200 hours of manual effort annually. The following diagram (Fig. 1) shows how this effort is distributed seasonally (for details see Appendix). It assumes that everything is done to reduce seasonal labour peaks by doing maintenance and repair work, hedge cutting and mucking out, &c., in relatively slack periods.

The peak demand for labour arises, of course, in the two planting periods; about 400 hours are required in February, March, and September. Similar demands are made in July because of the sugar-cane harvest and uprooting Napier grass. The remaining months require approximately 300–50 man-hours. It should be noted that, for this exercise, coffee picking is related to a yield of 5 cwt. of parchment an acre. Normal yields of African-grown coffee are substantially greater than this. If 10 cwt. of parchment an acre is assumed, 40 hours more would be needed in October, November, December, and January.

A family on a holding of this size is unlikely to provide more than two effective working adults—the man and his wife. With recent develop-

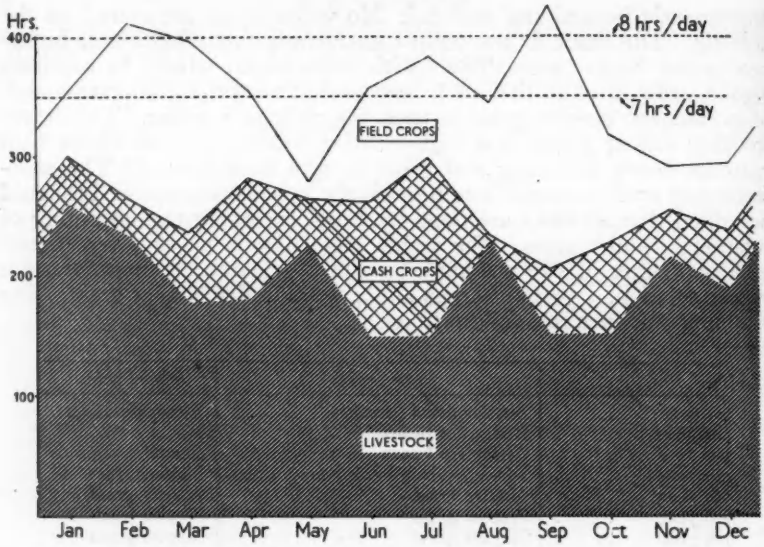

FIG. 1. Seasonal distribution of labour requirements on holding of 3·46 acres.

ments in education children spend their time at school instead of doing odd jobs on the holding as formerly. Assuming these two adults to work 300 days annually, for 6, 7, or 8 hours daily, the following man-hours would be available:

	Hours per day		
Man-hours from two adults:	6	7	8
per year	3,600	4,200	4,800
per month	300	350	400

On paper, if the pair worked 7 to 8 hours a day for 300 days annually the plan could just be carried through, but of course in practice the margin is too fine. Moreover, to assume that even the most enterprising cultivator would maintain such sustained endeavour is more than heroic. In any case, one cannot assume a full-time effort from the woman who, in addition, must attend to the daily chores, leaving her no more than 4 or 5 hours for fieldwork.

This plan achieves notable improvements over Reserve conditions. It maintains fertility and provides a substantial cash income[1] in addition to family subsistence, but it clearly cannot be worked by family labour alone. Though fulfilling other important requirements it fails in this important respect and cannot therefore claim to be a viable farm system. To prove workable the plan must either employ paid casual labour at

[1] In 1956 net income was estimated to be £22 an acre and this was before the coffee had come into bearing.

appropriate times or be suitably modified within the capabilities of family labour. This could be achieved by substituting oxen for hand cultivations. Two oxen might be hired for this work or they might be maintained on the holding. But the cost of this latter alternative would be the annual value of milk produced by two cows which would have to go to make room for the oxen. Because of its harvest peak, sugar-cane would have to be replaced by another crop with more even labour demands. These two modifications together would bring both total and seasonal labour needs within the reach of family labour. It would, however, reduce the cash income of the holding.

The second example, dealt with more briefly, is a plan actually in operation on an African holding of 11·9 acres in the Central Province. The holding is above the average in size and because of the exceptional ability of the owner, also in earning capacity. A 7-year rotation of 4 years crops and 3 years ley is run on 4·4 arable acres. The cropping sequence is as follows:

	Long rains	*Acres*	*Short rains*
1st year . . .	English potatoes	0·62	Oats (hay)
2nd year . . .	Beans	0·63	English potatoes
3rd year . . .	Maize	0·63	Beans
4th year . . .	Maize (i/p)	0·63	Grass
5th year . . .	Grass	0·63	Grass
6th year . . .	Grass	0·63	Grass
7th year . . .	Grass	0·63	Beans

The remaining area comprises: 0·47 acres sweet potatoes, 0·27 acres cassava, 0·83 acres pineapples, 0·25 acres orchard, 1·86 acres Napier grass (mulch), 2·14 acres coffee (1·76 acres in bearing), 0·46 acres bananas, 0·26 acres trees, 0·64 acres homestead and vegetables, and 0·31 acres road. Stocking includes 100 hens, 2 sows (producing 30 porkers), 3 ewes and lambs, and 2 oxen. All seed-bed cultivations are done by oxen. With such a relatively large coffee acreage labour needs are much affected by the yields obtained. If yields run at 10 cwt. parchment an acre the coffee acreage requires over 5,000 man-hours annually, i.e. more than two full-time labourers; the total holding requirements are over 8,500 man-hours[1] or four full-time labourers.[2]

Information relating to income and expenses was obtained from this holding in 1956.[3] In this year a very high coffee yield of 20 cwt. an acre was obtained at which level total labour needs would be about 11,000 man-hours. In the event six full-time labourers were hired together with some casual labour. This labour force would comfortably cope with all tasks on the holding (including those in footnote 1). It

[1] This total excludes time for harvesting cassava, pineapples, fruit and vegetables, and also the management of stock.

[2] Assuming a 7-hour working day which is that normally done by hired labour on European farms. Cf. [5].

[3] The following estimates were obtained: gross income £97 an acre, expenses £33 an acre: net income £64 an acre. With coffee yielding 10 cwt. instead of 20 cwt. an acre net income would have been approximately £47 an acre at prices then prevailing.

follows that little if any physical labour was required from the farmer or his family. Nevertheless, on a holding of this complexity and productivity he would no doubt be fully occupied supervising labour and exercising his other managerial duties. Indeed, he epitomizes the capitalist farmer, whose like government will no doubt nurture in its endeavour to create a stable, property-owning, middle class.

It should be added that the purpose of this second example is not to prove or disprove anything concerning its labour organization but more to illustrate the considerable physical effort required to carry through a complex farm system on a holding of this size. Nor should the first example be taken as a general criticism of farm-planning activities in Kenya.

Discussion

The results of recording labour expended on certain crops and stock are given above, and an attempt is made to illustrate the importance of relating the labour needs of farm plans with the availability of manual effort. It might be thought that this is scarcely the concern of the farm economist. His interest is not so much with the physical aspect of labour usage as with the optimal combination of all farm resources, and hence with maximizing net income. But where the labour input is the preponderent cost item, as in tropical peasant farming, maximization of income is virtually achieved when labour is utilized in its most profitable alternatives. In seeking to increase the economic efficiency of farm-resource use and hence net income, the first step is the assembly of labour information—the main limiting factor. The next step is the combination of input, output, and price data, by budget or linear programme methods, to achieve an optimal economic solution [6]. The increasing commercialization of peasant farming will no doubt require the increasing use of these methods.

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APPENDIX

Seasonal Distribution of Labour Requirements on Holding of 3·46 acres (See p. 88)

APPENDIX

Seasonal Distribution of Labour Requirements on Holding of 3·46 acres (See p. 88)

Crop	*Acres*	*Jan.*	*Feb.*	*Mar.*	*Apr.*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*	*Total hrs.*
Maize	0·75	30	138	40 26 60	56				36	35				421
Beans	1·25			19			31			138 12	49		20	269
Sweet potatoes	0·25	11					8	50	50 8	20	25			172
Napier grass	1·00	15	15	15	15	15	15 39	33	15	15	15	15		237
Bananas	0·37				10	10	10	10	7					47
Vegetables	0·06		17	6		7	7							37
Coffee	0·25	42	15	18 36	36 58		11 40			18 36	36 42	42	11 42	483
Sugar cane	0·53					19	45	140						204
Extra Napier grass	0·21											20	21	41
Stock Milking Maintenance	.. ..	96	96	96	96	96	96	96	96	96	96	96	100	528 628
F.Y.M.	..	80	90	30		80			80					360
Napier grass 'cut and carry'	..	52	48	52	52	52	52	52	52	52	52	52	52	620
Overheads	3·46	33			33							65	33	164
Total (hrs.)	..	359	419	398	356	279	354	381	344	422	315	290	294	4,211

THE POSSIBLE EFFECTS OF CHANGES IN LAND TENURE ON FARMING AND SOIL FERTILITY IN NORTHERN NIGERIA

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Summary

The prevailing systems of land tenure in Northern Nigeria are briefly described, and their relative advantages and disadvantages in relation to the level of husbandry and soil fertility are discussed.

It is concluded that the trend from communal ownership, through tenancy, towards freehold possession, is on the whole beneficial, in spite of the concomitant tendency towards fragmentation.

IT is necessary to explain the prevailing systems of land tenure in Nigeria, and the changes which are taking place before their effects are discussed. One of the few things common to all the tribes in Nigeria is the communal ownership of land [1]. When the British arrived there was almost a complete absence of any idea of individual possession.

The tendency in the past has often been for administrative officers to try to keep in being a way of life that existed when the British arrived, and yet at the same time to encourage modern material advances. In the case of land tenure many officers favoured communal ownership under the chief, in preference to ownership by the individual, even where the old tribal system was breaking down. One of the advantages was that land could be taken over for roads and buildings at a very low cost. In practice it proves virtually impossible to stop the development of a freehold system, which is almost inevitable when the population increases beyond a certain limit, and the people begin to yield to modern economic developments.

Lord Lugard [2] gave an excellent description of the sequence of land tenure: 'In the earliest stages the land and its produce is shared by the community as a whole; later the produce is the property of the family or the individual by whose toil it is won and the control of the land becomes vested in the head of the family. When the tribal stage is reached, the control passes to the chief, who allots unoccupied land at will, but is not justified in dispossessing any person or family who is using the land.' Northern Nigeria had in the main reached this stage when the British arrived and nearly all the country is still controlled by this system of tenure. Lord Lugard continues: 'later still when the pressure of population has given to the land an exchange value, the conception of proprietary rights emerges, and sale, mortgage and lease of the land apart from its uses is recognized. These processes of natural evolution, leading up to its individual ownership, may, I believe, be traced in every civilization known in history.' In the heavily populated area around Onitsha in the Eastern Region this stage has been reached and the land is said to be worth over £100 an acre.

[Empire Journ. of Exper. Agric., Vol. 28, No. 110, 1960.]

There are some steps between the tribal stage and the idea of individual ownership. At some point the economy places too great a strain on the public spirit of the traditional authorities charged with the allocation of land, and the idea of value in terms of money appears. In the very heavily populated area of southern Tiv, for example, a man may return to his area from working 'abroad' in the Cameroons or elsewhere and request a piece of land to farm. Before the 'palaver' with the local Tior (District Head) even commences a 'dash' (gift) of approximately ten pounds must change hands although this is not official and will not usually be admitted.

In the main it is only around the large towns that the old idea of communal ownership under the chief is breaking down. The land around some cities in the north has been owned by the farmers for a number of years, and the titles are vaguely based on past rights. In some cases the land may actually be bought and sold, such as around Kano [3], while in others it has not reached this stage. As late as 1952 [4] the land in the area of Zaria city was rented or used by the owners, as its sale was not considered advisable by the landlords because their titles were based merely upon remnants of the right of fief, and the administrative authorities would probably intervene in any dealings.

In the end the land is bound to become freehold and owned by individuals, in certain areas, if not in the whole of the country. A similar tendency is occurring throughout Africa, as shown by a recent report [5] in which it is stated that 'it is in some of these areas [i.e. of dense population] particularly that the old customary communal tenures are no longer able to meet the needs of the people and are fast giving way to forms of individual tenure in the sequence described by Lord Lugard'.

This report further stated that where conditions are ripe individual land tenure should be encouraged. Rowling [3] also stated a similar view: 'the present theoretical ban [on land sale] is quite pointless and if it is not enforced, or unenforceable, had better be withdrawn'. In Kano area, now, for example, the power of the Emirate government over land in the vicinity of the city is practically reduced to acting as a registration authority.

The effect of the Islam religion on land tenure is also noteworthy. Both the pagans and the Muslims regard the chief as the trustee of the land for the community and, surprisingly, Mohammedan law does not seem to have had any effect on this system. Even in Muslim Emirates 'unbelievers' have the right of use over their farms. In practice great diversity prevails in the different courts, and in the past a change of Alkali (judge) could cause considerable migrations if he was known to be a man who was liable to disregard 'Maguzwa' (pagan Hausa) and 'Kitizu' (pagan Fulani) rights [6].

The Effects of Land Tenure on Farming and Soil Fertility

We have now seen that there are thus three main types of land tenure in the Northern Region: communal ownership, tenant farmers, and freehold possession. The effects that these three types of land tenure have on the general level of fertility of the soil will be discussed separately.

It is of particular importance, especially in an agricultural country whose wealth is largely based upon the fertility of its soil, to ascertain whether the natural evolution to freehold possession will have a bad effect.

Communal Ownership

The main disadvantage of this system soon becomes apparent. The farmer does not own his land, and its condition at the end of a cropping cycle is of little consequence to him, as he can always go to the chief and request a new site, and provided there is sufficient land he will be granted one. In areas of low population this shifting cultivation has few bad effects provided the land is given an adequate rest period. The effect of natural regeneration in restoring the fertility is greater in the high forest and to a lesser extent in the savannah than in the Sudan zone [7]. Thus a quicker turn-round is possible in the forest, and the population can rise higher before the effect on soil fertility is so noticeable.

The difficulties encountered in encouraging a farmer to improve the value of his farm are considerable. The individual value of planted fallows, farmyard manure, and fertilizers are now more fully appreciated than formerly, but the main difficulty is to get the farmer to put into practice the knowledge that has been gained [8]. It is difficult to persuade him to take the trouble to plant fallows or carry manure for long distances, and to spend money on fertilizers, when the land is not his to preserve.

Where land is becoming scarce communal ownership may have grave dangers to the whole community, and to the land concerned. It may be nothing more than a rather poor device for ensuring fair shares in a rapidly wasting asset. It may, by its failure to provide adequate incentive to the individual farmer to put effort and money into the land, discourage any attempt to conserve and improve it.

Tenant Farmers

The advantage of allowing tenant farmers, who are now all in the vicinity of the big cities, is that townsmen who have some spare time but no land are in a position to acquire the loan of a small patch for their own use. It also means that big landowners, who have more land than they can handle or who have become more interested in business than farming, and yet do not wish to give up their property rights, need not leave their farms idle but can make use of the land by letting it.

This is of particular importance in areas where the land is of high value but requires a considerable number of man-hours to work it efficiently. The intensively cultivated vegetable gardens around Kano or the sugar-cane plots in the vicinity of Zaria are examples of this type of farm. On the whole these farms seem to be fairly well managed by present standards and certainly not worse than the communally held land in the countryside.

The disadvantage of tenant farming is that the landlord may charge an excessive rent. The tenant may then be forced to overwork his land in order to get a sufficient reward. This state of affairs is not likely to occur in Northern Nigeria until land becomes generally scarce over the whole

country, for in extreme cases of this type, at the present time, the farmer can always move to another area.

Freeehold Possession

The advantage of freehold possession is that the farmer owns the land, and if he destroys it by bad farming the only way he can get another piece in the same neighbourhood is by buying it. Usually this is a sufficient punishment to deter him from ill-using his land and the fact that it increases in fertility means that the farmer is much more sympathetic to sound scientific advice. The author fully agrees with the report of the Conference on African Land Tenure in East and Central Africa [5] which states: 'the committee considers that where conditions are ripe individual land tenure should be encouraged'. This step changes the land from being worthless to becoming a valuable asset, and it immediately becomes important to conserve and improve it.

The argument against freehold tenure is that there is a danger of fragmentation, so that holdings cease to be of an economic size and a rise in the standard of the peasantry becomes impossible. The scattered fields lead to bad husbandry in heavily populated areas, as they cannot be worked as a unified holding. This is a serious drawback in modern European farming, but is it so bad in Northern Nigeria? Why is it important to have a holding in one unit?

There are three main disadvantages. First, if the holding is very fragmentary the farmer spends much of his time going from one field to another, but this is valid only if the farm is split into many small pieces at some distance from one another. In practice this does not seem to occur so much as one would expect [3]. Second, thefts are more difficult to prevent, although where farmers do not live on their farms but in villages, as in most of Nigeria, stealing is almost as difficult to control on a larger unified farm a long way from the farmer's house.

Third, mechanization is impossible where the land is split up into very small fields. This criticism is often advanced by agricultural advisers, but two important points must be considered. Arguments in favour of mechanization in Nigeria are usually based upon the assumption that development in the tropics will follow similar lines to those in Europe. However, the dangers of basing tropical agriculture upon methods used in temperate regions is now well known. Furthermore, in the author's opinion, mechanized farms in Northern Nigeria have on the whole been failures from an economic point of view; in fact, many units have now closed down and even mechanized rice ploughing is not progressing as was formerly hoped.

Hence, only liability to theft, and wasted time can be accepted as arguments against fragmentation due to freehold tenure, and even then only if fragmentation is excessive. On the other hand, there is the advantage that where a farmer owns a number of plots, they often cover different soil types where different crops will grow well. For example, a Kano farmer with half an acre of sugar fadama, a half-acre vegetable farm, and a one-acre groundnut farm will undoubtedly be better off in the end than a farmer with two acres of one type of soil. He can stand

price fluctuations in one commodity more easily, and there is a more uniform call on his labour resources.

One of the best and most heavily farmed areas in Northern Nigeria is around Kano city, where people go to the trouble of transporting manure or night-soil compost to their farms [8] which are often some miles away. This trouble is obviously considered worth while, as the land is scarce and belongs to the individual who farms it. It is noticeable that a few miles from Kano, where individual freehold rights have only recently developed [3], there are considerable areas of poor fertility [9, 10] which are undoubtedly due to faulty management. Whether these areas would have become infertile if freehold tenure had developed earlier, with the greater sense of responsibility that it brings, it is, however, not possible to say.

Land tenure also affects livestock owners. Farmers may realize that the pasture is limited, but this will not deter them from trying to increase their own personal herds. 'When it is everybody's interest to improve the pastures it is nobody's responsibility to do the work' [11].

Even though it seems that freehold tenure offers more hope for better farming than the old communal system it is not wise to put sole faith in Arthur Young's 'Magic of Property'. This problem of land tenure is fundamental to the future of farming in the tropics and requires much more attention that it receives at present.

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SOME GENETIC PARAMETERS OF THE WATER BUFFALO

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Summary

An analysis has been made of the milk records of buffaloes from approved dairy farms in India compiled by the Imperial Council of Agricultural Research in 1941.

The repeatability of milk yield of 0·45 obtained for this population is very similar to the mean of the estimates previously reported for other buffalo populations and to the estimates derived from dairy cattle populations of tropical as well as temperate origin.

The repeatability of length of lactation of 0·24 is also similar to corresponding estimates for other buffalo populations.

The heritability of milk yield was found to be $0{\cdot}16 \pm 0{\cdot}11$ and that of length of lactation $0{\cdot}06 \pm 0{\cdot}11$ on the basis of 413 daughter-dam pairs. The conclusion is drawn that the heritability of production traits in the water buffalo is probably low, but that more data are required to establish that within narrow limits.

WHEREAS the African buffalo, *Bos caffer*, has never been successfully domesticated, its Asiatic relative, *Bos bubalis*, which traces back to Syria where it was found in Neolithic times, has been domesticated since the Christian era. It is a valuable dairy and work animal in India, Ceylon, and many parts of south-east Asia and is also used to some extent as far west as Bulgaria and Italy [1].

Physically the water buffalo is a large-framed heavy beast with great depth of body, almost hairless and with a dark pigmented skin. The usual colour is black or dark grey. The head is long and narrow with the flattish horns either long and curved back along the neck or short and curled up at the ends. The rump is steep and the hook and pin bones are prominent. The tail is short. The udder is well developed.

Milk from the water buffalo is very rich in fat, usually rating over 7 per cent., so that on the basis of butterfat alone the water buffalo competes favourably with domestic cattle. This high butterfat content is of considerable importance in the tropics where clarified butterfat often forms the main produce from dairying, due to lack of adequate refrigeration facilities for liquid milk.

Interest in the genetics of the water buffalo dates back only a few years. It has been established that a high degree of variation exists in respect of characters of economic importance in the water buffalo. This is evidenced by the records of milk production for breeds such as the Murrah in India which range from about 3,000 to 5,000 lb. per lactation under farm conditions, with many individual cows yielding up to 10,000 lb. The possibilities for attaining higher production among buffaloes are therefore assured. The genetic fraction of the variance appears to be such that the methods of selection and improvement that have shown success with dairy cattle may be applied equally well to herd improvement work with the water buffalo. Some estimates of the

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repeatability and heritability of milk production in the water buffalo have been provided by Asker *et al.* [2], Alim and Ahmed [3], Ashfaq and Mason [4], and El-Itriby and Asker [5]. They showed that repeatability was of the order 0·36 to 0·55 while heritability was around 0·18 to 0·24. These figures are in close agreement with the estimates from dairy-cattle populations in the tropics.

With regard to other economic characters associated with milk production, the genetic parameters of zebu cattle and water buffaloes are again quite comparable. For age at first calving, Asker *et al.* (1) found in Egyptian buffaloes that the heritability was 0·13 with a mean age at parturition of about 38 months. For calving interval, repeatability estimates [2, 3, 4, 5, 6] have ranged from 0·05 to 0·15, while heritability as measured by the correlation between 99 half-sibs in El-Itriby and Asker's study [5] was close to zero. Alim's estimates [6] of heritability were rather higher, but since his daughter-dam correlations and regressions were not computed on an intra-sire basis, they are likely to have included part of the environmental correlation between daughters and dams. The water buffalo is notoriously a shy breeder, usually calving once in 500 or 550 days. But improved management practices would undoubtedly reduce the length of the calving interval, as evidenced by Ashfaq and Mason's analysis [4] of the Pakistani buffalo, where a decrease in calving interval from 20 months to less than 13 in four years was noted. The repeatability and heritability of the two main components of the calving interval, namely length of lactation and length of dry period, have also been investigated. Values ranging from 0·16 to 0·26 and from 0·12 to 0·18 respectively have been obtained for the repeatability of the two traits, while the corresponding heritabilities were found to be of the order 0·11 to 0·14 and 0·02 to 0·18 respectively.

Material

The Animal Husbandry Bureau of the Imperial Council of Agricultural Research compiled and published in 1941, in two parts, the milk records of cattle in approved dairy farms in India. Part I listed the milk records of cows and part II that of buffaloes. The former have already been used by the author for a study of the repeatability and heritability of milk yield in crosses between Indian and European breeds of dairy cattle [7], while the latter provided the material on which the present study was based. Deficiencies in the records published in the I.C.A.R. Miscellaneous Bulletins of 1941 have been discussed earlier [7], and it was concluded that the material was nevertheless suitable for genetic analyses. It was therefore considered that an analysis of the buffalo records [8] would also be worth while and the results of this analysis are presented here.

Results

Repeatability

Table 1 shows the results obtained from a study of the intra-herd repeatability of total milk yield in the population using the data relating to home-bred animals.

TABLE 1. *Repeatability of Milk Yield*

Lactations correlated	*No. of cows*	*No. of herds*	*Within-herd repeatability*
1:2	846	32	0·51
2:3	621	32	0·49
3:4	523	32	0·47
1:3	620	32	0·37
2:4	527	32	0·48
1:4	525	32	0·38
Average	610	32	0·45

The overall mean value of 0·45 is very similar not only to the mean of the estimates previously reported from other buffalo populations, but also to the estimates derived from dairy cattle populations of tropical as well as temperate origin. The detailed trend of the results between different lactations is also essentially similar in that the correlation between consecutive records is usually greater than that between non-consecutive ones.

The repeatability of length of lactation was studied on a lesser number of cows than that used for milk yield, in view of the lack of data relating to length of lactation in some of the records. The results of this study are presented in Table 2.

TABLE 2. *Repeatability of Length of Lactation*

Lactations correlated	*No. of cows*	*No. of herds*	*Within-herd repeatability*
1:2	526	32	0·26
2:3	403	31	0·23
3:4	281	30	0·27
1:3	396	31	0·17
2:4	277	30	0·33
1:4	269	30	0·19
Average	359	31	0·24

The repeatability of length of lactation averaged 0·24 and is only about one-half of the repeatability of milk yield. This value is also similar to previous estimates of the repeatability of length of lactation in buffalo populations elsewhere.

Heritability

In the material investigated, the only available data relating to dams that could be used for daughter-dam comparisons were figures showing particulars of the best lactation performance of the dams without reference to lactation number. The heritability of milk yield was therefore computed by calculating the intra-sire daughter-dam regression on the basis of the highest yield of dam and the highest available yield of daughter. For the heritability of length of lactation, the lactation periods in which the highest milk yields were recorded by dam and daughter

were used. The heritability estimates may, on account of the absence of corrections for the effects of age on milk yield and lactation length, be slightly lower than the true values, but the discrepancy should not be large [9].

The results obtained by calculating the regression of daughter on dam within sire and doubling the regression are given in Table 3.

TABLE 3. *Heritability of Milk Yield and Length of Lactation*

Character	*No. of daughter-dam pairs*	*No. of sires*	*Heritability*
Milk yield	413	89	0·16
Length of lactation	413	89	0·06

The heritabilities of 0·16 and 0·06 of milk yield and length of lactation respectively, shown in this table, have a high standard error of 0·11. One cannot place much emphasis on these values as they are not significantly different from zero. Previous estimates of the heritability of production traits in the water buffalo also cannot be given much weight, because they have all been based on an even smaller volume of data than the present estimates. The lowest estimate reported in the literature for the additively genetic fraction of the variance in milk yield in buffaloes was 0·18 based on an analysis of variance between and within sires of 278 animals at the Government Buffalo Breeding Farm, Bahadurnagar, Pakistan [4]. The highest estimate, on the other hand, was 0·24 for milk yield in Egyptian buffaloes [2] based on only 44 degrees of freedom. For length of lactation, previous heritability estimates were 0·11 [2] and 0·14 [5], both of which were again based on a very small volume of data.

In the present investigation the available data were also tabulated for the estimation of the genetic correlation between milk yield and length of lactation in the water buffalo. But the low values of heritability found for the two characters meant that the standard error of the genetic correlation would have been of the order 0·80, and this would have rendered an estimate of the genetic correlation valueless.

Discussion

The estimates of 0·16 and 0·06 for the heritability of milk yield and lactation length in water buffaloes presented here, though based on the largest volume of data hitherto available in this species of farm animals, are nevertheless not significantly different from zero. It cannot therefore be considered that the genetic parameters of the water buffalo have yet been established within narrow limits. It is, however, interesting to note that during the period covered by the present records, the heritability of milk yield in a closely comparable population of crossbred European × Indian dairy cattle in approved dairy farms in India was estimated to be ·19 oon the basis of 1,102 daughter-dam pairs [7]. The conclusion may therefore be drawn that the heritability of milk production traits in the cow and

buffalo populations covered by Miscellaneous Bulletin No. 36 of the Imperial Council of Agricultural Research in India is probably low.

The repeatability estimates, however, seem to be more in line with the findings from other cattle populations. A sufficient volume of data was available in the present study for estimating repeatability, and it was found that the repeatability of milk yield in the water buffalo was 0·45 and that of lactation length 0·24. Although these figures may be regarded as upper limits to the heritabilities, it is clear that a much larger volume of recorded information is needed if we are to establish the role of heredity in productivity in these animals with a high degree of accuracy.

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STUDIES ON EGYPTIAN BALADI GOATS. II SOME FACTORS AFFECTING MORTALITY RATE

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Summary

Records kept on the University of Alexandria Farm for a flock of Egyptian Baladi goats were analysed to study the effects of different factors that may influence percentage of mortality rate from birth up to the fourth month of age. The study included 560 kids, and covered a period of fifteen years from 1943 to 1957. The following results were obtained.

Birth weight showed great influence on mortality rate; the heavier the weight at birth the lower was the mortality rate among the newly born kids. Mortality rate was 100 per cent. among kids that weighed less than ½ kilogramme at birth, while it was 12 per cent. among those weighing more than 1·5 kilogrammes.

Mortality rate was high at the first kidding, then it decreased up to the fourth, i.e. when the dams were about 3·7 years old. There was a tendency for mortality rate to increase once again after that.

No significant sex difference was observed in mortality rate. Type of birth had great effect however; mortality rate was much higher among kids born as triplets and quadruplets than those born as singles and twins.

Season and year showed significant effects on mortality rate.

In a flock of goats the number of kids that can survive to weaning time, i.e. to the fourth month of age, is of great importance to goat breeders.

The present investigation was undertaken to determine the influence of some factors that may affect mortality among kids from birth to weaning, i.e. birth weight; dam's weight and age; sex and type of birth; season; and year.

Material and Methods

Data used in the present investigation were taken from the records of the Alexandria University Farm. They cover the period from 1943 to 1957, and included 560 kids, from 257 kiddings.

Kidding took place all the year round, but the majority of kids were delivered during the period from November to February (winter-born kids). Those born during the period from March to May inclusive are referred to as summer-born kids.

All the kids were similarly treated and under the same environmental conditions. Feeding and management of the flock have been reported in a previous paper [1].

Birth weights were recorded within a few hours of birth and subsequent weights were taken at monthly intervals.

Results

Mortality rates within 24 hours from birth, and from then up to weaning time (up to 4 months of age), were 17·9 and 19·2 per cent.,

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respectively. These give a total mortality of 33·7 per cent. (Table 1). These results are much higher than those reported for sheep by Venkatachalam *et al.* [2], Terrill [3], Ragab *et al.* [4], and Karam [5].

Birth Weight

The average birth weights were 0·96±0·20, 1·14±0·35, and 1·41±0·56 kilogrammes, for kids dying at (within 24 hours of) birth, surviving up to weaning time, and those living beyond weaning, respectively.

TABLE 1. *Effect of Year on Mortality Rate*

	At birth			*From birth to weaning*			*Total*	
Year of birth	*No. kids born alive*	*No. kids died*	*Mortality %*	*No. kids born alive*	*No. kids died*	*Mortality %*	*No. kids died*	*Mortality %*
1943	8	2	25·0	6	1	16·7	3	37·5
1944	25	2	8·0	23	2	8·7	4	16·0
1945	29	2	6·9	27	6	22·2	8	27·6
1946	14	3	2·1	11	5	45·5	8	57·1
1947	12	3	25·0	9	3	33·3	6	50·0
1948	13	3	23·1	10	7	70·0	10	76·9
1949	17	2	11·8	15	1	6·7	3	17·6
1950	12	3	25·0	9	1	11·1	4	33·3
1951	30	7	23·4	23	1	4·4	8	26·7
1952	39	7	19·0	32	4	12·5	11	28·2
1953	63	9	14·2	54	12	22·2	21	33·3
1954	36	9	25·5	27	2	7·4	11	30·5
1955	103	17	16·5	86	19	22·1	36	35·0
1956	49	6	12·2	43	6	14·0	12	24·5
1957	70	18	25·7	52	12	23·1	30	42·9
Total or percentage	520	93	17·9	427	82	19·2	175	33·7

TABLE 2. *Effects of Birth Weight on Percentage Mortality Rate*

	Birth weight in kilogrammes				*Total or percentage*
Item	*Less than 0·5*	*0·5–1·0*	*1·1–1·5*	*1·6 and over*	
No. births .	26	129	130	84	369
No. deaths .	26	63	36	10	135
Mortality %	100·00	48·8	27·7	11·9	36·6

Mortality rates among kids born alive are shown in Table 2. Birth weight of kids had a significant effect on mortality rate. The heavier the kids were at birth the less their mortality rate. The present results agree with those reported by various workers on sheep [2, 3, 4, 5, 6]. It may be concluded that goat breeders should give more attention to obtaining heavier kids at birth, in order to minimize the mortality rate.

TABLE 3. *Effects of Dam's Weight, and Age, on Kid's Mortality at Birth*

Sequence of kidding	*No. of dams*	*Dam's age (years)*	*Dam's weight (kg.)*	*% Mortality among the various types of birth*			
				Singles	*Twins*	*Triplets*	*Quads*
1	43	1·6±0·1	21·4±1·7	24·1	28·3	..	..
2	35	2·3±0·1	27·1±1·8	15·8	20·9	42·8	..
3	36	3·0±0·1	31·2±1·7	15·5	28·0	35·0	46·6
4	27	3·7±0·3	32·8±2·0	10·2	15·0	25·4	45·1
5	21	4·1±0·2	33·3±1·8	25·1	27·3	40·5	..
6 and over	31	6·5±0·4	34·4±2·5	26·2	30·3	38·6	36·0
Total or percentage	193	3·6±0·2	30·0±2·1	19·5	25·0	36·5	42·6

TABLE 4. *Effects of Sex and Type of Birth on Percentage Mortality Rate*

Type of birth	*Sex*	*At Birth*			*From birth to weaning*			*Total*	
		No. kids born	*No. kids died*	*Mortality %*	*No. kids born*	*No. kids died*	*Mortality %*	*No. kids died*	*Mortality %*
Singles	♂	30	3	10·0	27	6	22·2	9	30·0
	♀	22	2	9·1	20	2	10·0	4	18·2
Total or percentage		52	5	9·6	47	8	17·0	13	25·0
Twins	♂♂	62	13	21·0	49	9	18·4	22	35·5
	♀♀	26	7	26·9	19	9	47·4	16	61·5
	♂♀	68	25	36·8	43	33	76·7	58	85·3
Total or percentage		156	45	28·9	111	51	45·9	96	61·5
Triplets	♂♂♂	27	13	48·1	14	6	42·9	19	70·4
	♀♀♀	12	6	50·0	6	1	16·7	7	58·3
	♂♂♀	42	10	23·8	32	16	50·0	26	61·9
	♂♀♀	48	10	21·8	38	20	52·6	30	62·5
Total or percentage		129	39	30·2	90	43	47·8	82	86·1
Quadruplets	♂♂♂♂	8	2	25·0	6	2	33·3	4	50·0
	♀♀♀♀	..	..	..	..	..	..	..	..
	♂♀♀♀	12	6	50·0	6	2	33·3	8	66·7
	♂♂♂♀	12	8	66·7	4	3	75·0	11	75·0
	♂♂♀♀	16	5	31·3	11	4	36·4	9	56·3
Total or percentage		48	21	43·8	27	11	40·7	30	62·5
Grand total or percentage		385	110	28·6	275	113	41·1	223	57·4

Dam's Weight and Age

The percentage mortality rate as affected by dam's weight and age are shown in Table 3. There was a decrease in mortality rate among kids of all types up to the fourth kidding, after which it increased again. The results also demonstrate that mortality rates among triplets and quadruplets were higher than those among singles and twins.

It may be concluded from these results that good care should be given to young dams as well as to those giving a high percentage of

multiple births. Such does should be put on a reasonable plane of nutrition and exposed to a rather rigid selection, to minimize mortality among their offspring.

Sex and Type of Birth

Table 4 shows the effect of sex and type of birth on the percentage mortality. The results indicate that sex among the four types of birth had no significant effect on mortality rate, either at birth or up to weaning age. The total mortality rates for males and females were 26·0 and 28·6 per cent. at birth and 46·5 and 46·0 per cent. up to weaning time, respectively. Type of birth, however, had a significant effect on mortality rate, which was least among the singles.

TABLE 5. *Effect of Season on Kidding Mortality*

Season	*No. kids born*	*Mortality percentage*		
		At birth	*From birth to weaning*	*Total*
Spring . .	242	22·73	16·05	35·12
Summer . .	24	00·00	16·67	16·67
Autumn . .	157	25·48	17·09	38·22
Winter . .	164	19·51	16·67	32·99
Total or percentage .	587	21·64	16·52	34·58

Season

The mortality rates according to season of kidding are shown in Table 5. Among winter-born kids mortality rate was higher than for summer-born ones, the difference being statistically significant for mortality at birth. This is attributable to other unfavourable environmental conditions, such as improper housing, besides the cold weather.

In summer, although the number of kids born was small, none died at birth, whereas a high percentage died in the period from birth to weaning. This may have been due to the scarcity of green fodder during the nursing period.

Year

There was a noticeable yearly variation in mortality rates. At birth the average mortality ranged between 2·1 per cent. in 1946 and 25·5 per cent. in 1954. During the first four months of age the range was between 4·4 in 1951 and 70·0 in 1948. The total mortality ranged between 16·0 per cent. in 1944 and 76·9 in 1948. Differences in mortality rates among the various years are statistically significant. Such differences may be attributed to variations in feeding, weather, management, and other environmental agencies beside the genetical make-up of the flock.

Conclusions

The results of the present investigation indicate that the most important factors that influenced percentage mortality rate among kids in

a flock of goats were: the maternal influence, i.e. dam's weight, and age, her tendency to produce multiple births, besides seasonal and yearly effects.

It may be concluded that it is most profitable for breeders to select bucks from good producing does, persistent milkers, of large size, and from families of especially good conformation. Therefore a sound breeding programme should be planned to establish a flock of good genetic make-up. Such selection should result in improvement of the kid's birth weight, growth rate, and consequently mature weight.

It is also advisable to have only one kidding per year in the summer, with other environmental conditions at a reasonable level, especially as regards nutrition.

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FACTORS AFFECTING THE INCIDENCE OF BANANA WILT ('PANAMA DISEASE')

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Summary

In a glasshouse experiment with the banana variety Gros Michel, characteristic wilt symptoms appeared 6 weeks after inoculation with *Fusarium oxysporum f. cubense* in rapidly growing plants for which soil moisture remained at a steady, moderately high level, but not in plants subject to fluctuating soil moisture. Response to potassium fertilizer, as shown by leaf analysis, was appreciable with good soil aeration but undetectable with poor aeration. Severity of disease symptoms appeared to be inversely related to potassium uptake. The possibility of improving potash uptake by mature bananas sufficiently to induce wilt-resistance is discussed: a preliminary attempt to achieve this by peroxide applications has failed. Observations are made on a further small outbreak of wilt in Lacatan bananas, reported from Jamaica.

DURING investigations into Fusarium wilt of bananas, carried out in Jamaica, the author obtained information [1, 2] from experiments on small plants in the glasshouse. Caution is clearly necessary for interpreting such experiments in which conditions may greatly differ from those in plantations. Hitherto, one characteristic feature of susceptible varieties, such as Gros Michel, growing in the glasshouse, has been a lack of obvious wilt symptoms in infected plants, although early stages of fungal invasion of roots and rhizome closely resemble those occurring naturally. By analogy with behaviour in plantations, this was thought to be due to a check in growth occasioned by restricted root development, but this contention was not proved. Another problem arose from the failure of potassium fertilizers to influence infection in potted plants, or for that matter in plantations, despite strong circumstantial evidence that wilt is less severe on soils naturally rich in potassium. This paper describes an experiment bearing on these points and quotes some other recent observations.

Glasshouse Experiment

In June 1957 a consignment of small Gros Michel banana suckers was received from Jamaica for a glasshouse experiment at the Botany School Field Station, Cambridge. The suckers were divided into three sets of seven each, for planting in 14-inch pots. Set 1 was planted in a 1:1 mixture of light loam and clay-loam, it being intended that, with normal exposure to evaporation as in previous experiments, soil moisture would fluctuate whilst aeration would be only moderate. In set 2, with pots also normally exposed to evaporation, it was intended to provide fluctuating soil moisture combined with good aeration. For this purpose soil as used in the previous set was further well mixed with angular grit (0·2–0·4 cm.), gravel (1·0–1·5 cm.), and stones (6–8 cm.). This amendment, constituting about one-third of the mixture by volume, was intended to counteract

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the compaction occurring with regular watering. In set 3 it was aimed to maintain soil moisture at a steady, moderately high level, but without waterlogging, whilst aeration would be poor. This was achieved by standing each pot, filled with soil as in set 1, within a galvanized container, open above and below, and on a galvanized tray; the space between pot and container was then filled with moist peat. Within the pot, the soil surface was covered with a layer of moist Sphagnum moss.

After initial establishment sets 1 and 2 were watered twice weekly whereas set 3 was watered lightly each day, the peat being kept moist by regular addition of water to the tray and by sprinkling from above. The weather being cool, especially at nights, the glasshouse was given some heat almost throughout the experiment. Fluctuations of temperature were similar to those occurring during summer at Hope, Jamaica, daily maxima being about 35° C., with nightly minima below 25° C. for 4 to 6 hours only. In each set five out of seven plants were liberally supplied with potassium, each plant receiving 2 gm. commercial sulphate weekly as a 1 per cent. solution. Initial development was slow, probably owing to the 3-week transit of the suckers, but subsequent growth was rapid. After 6 weeks all plants except one in set 3, to act as control, were heavily inoculated by applying a maize-meal/sawdust culture of *Fusarium oxysporum f. cubense* (*c.* 3×10^9 viable spores) to the soil surface. From the first, plants in set 3 grew faster than those in the other two sets, and within 6 weeks of inoculation several showed characteristic wilt symptoms, such as buckled petioles, narrow heart-leaf, and split pseudostem. None of these symptoms appeared in the uninoculated plant or in the other sets, although in set 1 the lower leaves became markedly yellow. Eight weeks after inoculation plants were taken up and examined for rhizome infections, at which stage there was still ample room for root growth. Symptoms appearing in the three sets of plants are recorded in Table 1.

TABLE 1. *Symptoms appearing in Gros Michel grown in Pots under Various Conditions of Soil Moisture and Aeration, and inoculated with* Fusarium oxysporum f. cubense

Set	*Probable soil conditions*		*Symptoms visible 6 weeks after inoculation*			*Rhizome infections 8 weeks after inoculation (no./plant)*
			Yellowing (mean no. of leaves/plant)	*No. of plants with:*		
	Moisture	*Aeration*		*Buckled petioles*	*Narrow heart-leaf*	
2	Fluctuating	Good	0·7	0/7	0/7	12
1	Fluctuating	Moderate	3·5	0/7	0/7	13
3	Steady, fairly high	Poor	2·2	3/6	5/6	11

The heavy inoculation had caused rhizome infections through nearly all the first-formed roots, which were of similar abundance in each set, and secondary rotting was often prevalent. This was unfortunate in that any minor effects of soil conditions on root infection would have been obscured, but at least the lack of obvious wilt symptoms in sets 1 and 2

cannot be ascribed to any scarcity of infections. Apparently with high glasshouse temperatures evaporation is so rapid from normally exposed pots that growth is seriously checked when watering is intermittent. Even when roots and rhizomes are heavily infected, this brake on growth is sufficient to prevent characteristic wilt, by contrast with rapidly growing plants not restricted by lack of moisture. This situation occurs in affected plantations, checks to growth often causing a temporary decline in visible wilt incidence. Yellowing of the lower leaves was thought to be a symptom of incipient wilt, as appears likely from the observations of Stover [3]. If this was so, the difference between sets 1 and 2 may be significant, especially when considered in relation to potassium uptake. There was no evident difference with respect to symptoms, within the three sets, between plants receiving and not receiving potash.

These results suggest that banana wilt may be reliably induced in the glasshouse by providing sufficient root space, at least 15 kg. soil being desirable, and maintaining soil moisture at a moderately high level. The results also serve to correct an erroneous interpretation of earlier experiments. Whilst it remains true that fluctuating soil moisture facilitates root infection by *F. oxysporum f. cubense*, it can no longer be claimed that a steady soil moisture content necessarily prevents it. The results of pot experiments with bagasse, which appeared to suppress root infection, together with some minor observations, were originally considered to support this belief, but most probably the 'bagasse' effect was due to retarded root growth, as occurred in field experiments. Root growth was profuse at the end of such experiments, but records suggest that most roots were immature. This retardation would greatly have reduced the number of potential infection courts and could well have arisen through shortage of nitrogen, as evidenced by occasional leaf chlorosis.

With each plant, after examination for infection, dry weights of roots, rhizome, and pseudostem+leaves were determined. The potassium content of the second leaf was estimated, the small plants providing insufficient material for analysing the first leaf, which from the work of Hewitt [4] might well have had a higher potassium content. Table 2 gives a summary of the results obtained. Mean rhizome weights were very similar (*c.* 35 gm.) in the three sets and are omitted. The better growth of set 3 is clearly shown by the dry weights. The ratio, dry weight of pseudostem+leaves : dry weight of roots, is appreciably higher in this set than in the other two, but there is no evidence to show whether this factor contributed to development of wilt symptoms. Data from the single uninoculated plant suggest that root damage associated with invasion by *F. oxysporum f. cubense* was mainly responsible for the high shoot : root ratios obtained in this experiment.

Leaf potassium contents are of considerable interest. The mean content (per cent. K_2O) in six plants not given fertilizer was 5·46 whereas that in fifteen given potassium was 5·94. These values are somewhat higher than those quoted by Hewitt [4] for mature bananas. The mean content of available potassium (p.p.m. K_2O) of untreated soil was 160 at the end of the experiment, that of soil given potassium being 300: thus many plants showed an increased uptake with added potassium although

TABLE 2. *Dry Weight and Leaf-Potash Content of Gros Michel Plants grown in Pots under Various Conditions of Soil Moisture and Aeration*

A. Data from sets of 5 plants, each inoculated with *F. oxysporum f. cubense*

Set	Probable soil conditions		Mean dry weight (gm.)		Pseudo-stem/roots	Mean $\%K_2O$ in oven-dry leaf	No. showing response to potash
	Moisture	Aeration	Pseudo-stem	Roots			
2	Fluctuating	Good	53	9	5·8	6·5	4
1	Fluctuating	Moderate	46	9	5·2	5·9	2
3	Steady, fairly high	Poor	103	14	8·0	5·4	0
B. Corresponding data from 1 plant, not inoculated							
3	Steady, fairly high	Poor	145	35	4·2	5·2	0

the potassium status of the soil was initially far from low. Response to potassium fertilizer differed in the three sets: in set 2 with well-aerated soil it was appreciable, whereas in set 3 with poor aeration there was none, even in the uninoculated plant with a well-developed root system. It is possible that the greater potassium uptake in set 2 was due to a reduction in base-exchange capacity of the soil through admixture with stones, allowing more direct uptake after fertilizer applications; however, the nature and amount of the amendment are thought to render this explanation less likely than an effect due to improved aeration. The effect of soil aeration on potassium uptake is well known in some other plants, as shown, for instance, by Hammond, Allaway, and Loomis [5], and may be of special significance in the banana which is highly demanding for this nutrient. In the experiment just described, severity of disease symptoms increased as uptake of potassium diminished. It seems possible that in many banana plantations potassium uptake is limited by inadequate aeration, to the detriment of wilt-resistance; conversely, the frequent association of healthy plantations with well-aerated soils rich in potassium seems highly significant. Also in connexion with wilt-resistance, it is interesting to note that Hewitt [4] found nitrogen application to depress leaf potassium content in some instances.

Other Observations

The greater uptake of potassium by young bananas in conditions of good soil aeration in the glasshouse raises the possibility that this might be achieved under field conditions. Observations suggest that to gain significant wilt-resistance Gros Michel bananas must take up considerable amounts of potassium from the soil, which is almost certainly difficult to attain in practice. Wiersma and Mortland [6] note that oxygen supply is likely to limit growth of beet when the diffusion rate of oxygen in soil is low, and they have shown that in such conditions application of peroxide to the soil may help to alleviate this deficiency. A small pilot experiment to test application of peroxide was recently set up in Jamaica at a site where wilt had been prevalent. The incidence of wilt in replanted Gros Michel bananas was in fact no different in a set regularly

watered with dilute hydrogen peroxide (applications being comparable with those in the work quoted above) than in an untreated set. This experiment, in which all plants received liberal potassium applications, is being repeated but with one set receiving initial soil treatment with calcium peroxide.

A recent small outbreak of wilt in Lacatan bananas on an alluvial soil in Jamaica provided the opportunity to compare the root-infecting capacity of the Fusarium involved with a typical Gros Michel isolate. A small inoculation experiment was set up with Lacatan bananas, running concurrently with the one already described. No difference in root-infecting ability between the two isolates was detected, a result in accordance with previous work [2]. The persistence of wilt symptoms at this site in the hitherto resistant Lacatan variety, in the absence of obvious pre-disposing factors such as temporary waterlogging or heavy applications of nitrogen fertilizers, is puzzling and potentially serious, though outbreaks have occurred before. It is possible that a strain of *F. oxysporum f. cubense* has arisen which differs not so much in an increased ability to infect Lacatan roots but in ability to cause more extensive damage to this variety once established. This possibility could be adequately tested only with mature plants. It is perhaps equally likely that the strain involved differs little from existing ones but that some factor is lowering the resistance of Lacatan roots to infection. In this case suspicion would naturally fall on eelworm attack, now increasingly prevalent in the island, and recorded also in central America by Stover and Fielding [7]. Breakdown of wilt-resistance from this cause has been demonstrated in cotton by Holdeman and Graham [8]. In recent pot experiments with the resistant Cavendish banana, related to Lacatan, it was noted that *F. oxysporum f. cubense* readily became established in portions of rootlet invaded by eelworms, but very seldom entered intact rootlets. However, it is premature to explain the present wilt outbreak in this way: although eelworm attack is known to occur at the site in question, it is worse in many other places where *F. oxysporum f. cubense* is undoubtedly present and Lacatan is showing no sign of wilt.

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THE EFFECT OF INFECTION WITH TOBACCO-MOSAIC AND COWPEA YELLOW-MOSAIC VIRUSES ON THE GROWTH RATE AND YIELD OF COWPEA IN NIGERIA

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Summary

The effect of infection by the cowpea strain of tobacco-mosaic virus, cowpea yellow-mosaic virus, and a mixture of the two viruses on the growth rate, development, and yield of cowpea is described. Cowpea yellow mosaic is particularly severe in its effects on leaf area, flower production, and yield, but tobacco mosaic virus also causes some reduction in yield. The time of infection with both viruses is an important factor determining the losses caused.

LITTLE attention has been paid to the effects of viruses on the yield of cowpea (*Vigna unguiculata* L. (Walp.)) although their properties have been studied in detail [1, 2, 3, 4]. In Trinidad, Pickles and Thorold [5] obtained no significant difference between the yields of virus-diseased and healthy cowpeas although Dale [6] observed that virus infection caused an obvious check to the growth of young cowpea plants in the same country. Capoor *et al.* [7] reported that infected cowpeas in India produced few small pods, each containing few seeds.

Field crops of cowpea in Nigeria are often infected by cowpea yellow mosaic virus [4] and sometimes by tobacco mosaic virus [8]. Experiments were conducted by the author in 1958, on Moor Plantation, Ibadan, to assess the effect of infection by the two viruses on growth rate, flower production, and yield of the cowpea crop.

Methods

Three field experiments were carried out at Moor Plantation, Ibadan, from May till September 1958.

Experiment I was designed to compare the effect of infection by (*a*) cowpea yellow-mosaic virus, (*b*) cowpea tobacco-mosaic virus, and (*c*) a mixture of the two viruses, on the growth rate and yield of the variety, Dr. Saunders's Upright. The primary leaves were inoculated 2 weeks after sowing and thereafter samples of plants were taken at fortnightly intervals for detailed study. Experiment II was designed to study the effect of infection with cowpea yellow-mosaic virus inoculated at 2, 4, or 6 weeks after sowing, on the subsequent growth and yield of three varieties of cowpea—Dr. Saunders's Upright, New Era, and a local white variety.

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Experiment III was similar to Experiment II but cowpea tobacco-mosaic virus was used instead of cowpea yellow-mosaic virus and only one variety, Dr. Saunders's Upright, was tested.

A factorial layout with four replicates was used in each experiment. The cowpea seed was sown by hand at a spacing of 18 in. on 3-ft. ridges, each plot being 33 × 36 ft. Three seeds were sown per hole, the plants being thinned to one per hole a week after germination. Plants were inoculated when necessary with sap expressed from infected stock plants maintained in the insectary. An abrasive, kieselguhr, was incorporated in the inocula.

The same sampling procedure was followed in all three experiments. Twenty plants in a row were harvested from each plot at each sampling date and care was taken to ensure that the rows on either side of this were left unharvested throughout the experiment.

The plants were dug up and placed in polythene bags to prevent undue loss of moisture. The roots were cut off at the base of the stem and the leaves at the base of the petiole. After counting the leaves the laminae were separated from the petioles. The following observations were made on each sample:

1. Number of leaves.
2. Fresh weight of laminae, petioles, roots, and stems.
3. Dry matter expressed as a percentage of fresh weight of the above (based on sub-samples).
4. Area of the laminae.
5. Number of flowers.
6. Number of pods.
7. Fresh weight of pods.

The method for measuring leaf area was adapted from that described by Watson and Watson [9]. It was found that the best results were obtained when a punch of small cross-section (0·95 sq. cm.) was used to cut 20-gm. disks from a 200-gm. sample of lamina. The area of lamina per unit of fresh weight was then obtained and the total area was estimated by multiplying this figure by the total fresh weight of lamina. The difference between this estimate of the area of lamina and that calculated from making prints of the leaves on sun print 'Ammonax' paper and measuring the area with a planimeter was not significant.

Results

Experiment I

The effect of virus infection on leaf area, and on fresh and dry weights. Fig. 1 shows the effect of virus infection on the leaf area of cowpeas over a period of 10 weeks, commencing 2 weeks after inoculation when the plants were 4 weeks old. The standard errors were calculated for each sampling and the magnitude of the treatment differences required to reach significance is represented by a vertical line in each case.

Both viruses significantly reduced the leaf area at all samplings but the reduction was considerably less in plants infected with the tobacco-mosaic virus strain, since in all samplings from 6 to 14 weeks the leaf

area of plants infected with this virus was significantly greater than that of plants infected with either cowpea yellow-mosaic or with the mixture of viruses. In none of the samples did the leaf area of plants infected with cowpea yellow-mosaic virus differ significantly from that of plants infected with both viruses.

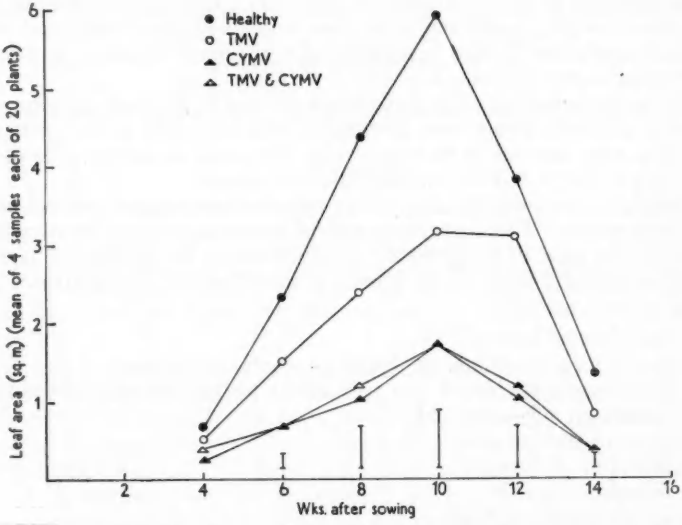

FIG. 1. Changes with time in the leaf area of healthy plants inoculated with virus two weeks after planting.

The effect of infection on the number of leaves produced was similar to that on leaf area but the mean fresh weight per leaf was significantly greater for healthy plants (Table 1).

TABLE 1. *Mean Fresh Weight per leaf (gm.) in Healthy Cowpea Plants and in plants Infected with Virus (mean of eighty plants)*

Virus	*Sampling (weeks after planting)*					
	4	*6*	*8*	*10*	*12*	*14*
Control . . .	0·89	1·16	1·23	1·45	1·21	1·11
CTMV . . .	0·70	0·99	0·95	0·99	1·13	1·20
CYMV . . .	0·61	0·72	0·66	0·89	0·88	0·74
CTMV+CYMV . .	0·68	0·75	0·79	0·92	0·94	0·98

Least significant difference ($P = 0·05$) = 0·252.

At all samplings between 6 and 14 weeks significant differences were found between the mean fresh weight per leaf of healthy plants and that of plants infected with either cowpea yellow-mosaic virus or with both viruses.

The area/fresh-weight ratio of the lamina varied slightly between samplings although it increased in virus-infected plants at the 12th and 14th weeks (Table 2). At most of the samplings it was reduced by infection by either or both of the two viruses.

TABLE 2. *The Area/Fresh Weight Ratio of Leaves of Healthy Cowpea Plants and in Plants Infected with Virus (mean of eighty plants)*

Virus	*Sampling (weeks after planting)*					
	4	*6*	*8*	*10*	*12*	*14*
Control . . .	43·4	43·8	42·9	41·7	45·1	42·2
TMV	38·6	39·8	38·4	38·9	42·9	43·1
CYMV . . .	36·9	35·5	36·6	36·5	38·3	40·2
TMV+CYM . .	37·2	38·3	37·8	37·9	40·5	40·5

Least significant difference ($P = 0{\cdot}05$) = 3·35.

It is apparent, therefore, that reduction in leaf area was accompanied by a reduction in the density of the leaf contents. Infection with the viruses also affected the fresh and dry weights of stems, petioles, and roots. Differences between healthy and infected plants were significant at all samplings but the reduction in growth caused by infection with cowpea tobacco-mosaic virus was significantly less than that resulting from infection by cowpea yellow-mosaic virus.

The effect of virus infection on yield. Virus infection adversely affected the production of flowers (Fig. 2).

With the exception of the sampling at the 12th week, infected plants produced a significantly lower number of flowers than healthy ones but the reduction caused by cowpea tobacco-mosaic virus was again significantly less than that caused by cowpea yellow-mosaic virus.

The effect of virus infection on the number and fresh weight of pods is shown in Table 3 where the results from the four samplings have been pooled.

Although virus infection significantly reduced the number and total weight of pods the weight of individual pods was greater in plants infected with cowpea yellow-mosaic virus than in healthy plants. No significant differences were recorded between the weight of seeds from pods taken from healthy and virus-infected plants.

Experiments II and III

The effect of time of infection on leaf area and pod weight. Time of inoculation with cowpea yellow-mosaic virus was found to be an important factor in the reduction in leaf area and yield (Table 4).

Because of a severe dry spell sampling was not continued after 12 weeks. However, the results indicate that in New Era and Dr. Saunders's Upright, early infection with cowpea yellow-mosaic virus caused a marked decrease both in leaf area and yield but that the effect became less obvious with later infection. Infection in the local white variety appeared to have little effect. The exceptionally low yield of this variety is

possibly due to the fact that it is usually planted later in the season when photoperiodic conditions are different. In all treatments (including controls) there was a reduction in leaf area with time. While a part of this

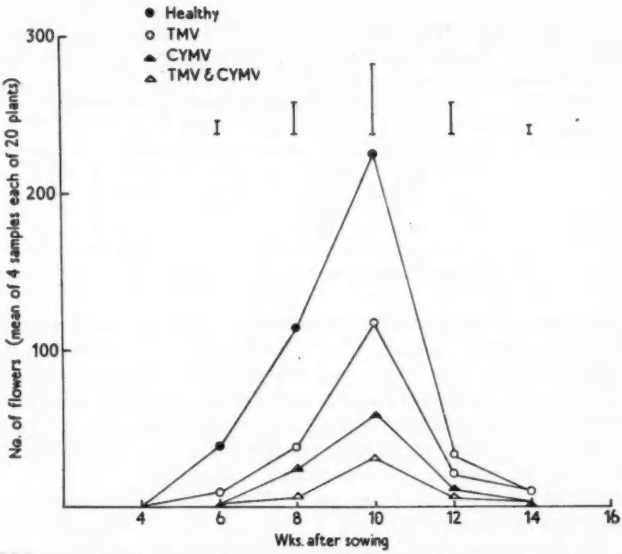

FIG. 2. Changes with time in the number of flowers produced by healthy plants and by plants inoculated with virus two weeks after planting.

TABLE 3. *Effect of Virus Infection on the Yield of Cowpea* (*mean of four batches of eighty plants*)

Virus	*No. of pods*	*Fresh weight of pods (gm.)*	*Mean fresh weight per pod*
Healthy . .	280·5	180·9	0·65
CTMV. . .	121·5	71·7	0·59
CYMV . . .	56·0	54·6	0·97
CYMV+CTMV .	30·0	32·5	1·08
Least significant difference ($P = 0·05$) . .	50·4	36·6	

reduction in infected plants was due to the effect of the virus the leaf number was also reduced in all plants by the extremely dry conditions during the period of the experiment.

As with cowpea yellow-mosaic virus late infection by cowpea tobacco-mosaic virus had less severe effects. The lower yield was again apparently related to a decrease in flower production (Table 5).

TABLE 4. *Effect of Time of Infection by Cowpea Yellow-mosaic Virus on the Leaf Area and yield of Three Varieties of Cowpea*[1]

Variety	*Age of Plants at time of inoculation (wks.)*	*Leaf area (sq. m.)*			*Fresh weight of pods (gm.)*		
		Time of sampling (wks.)					
		8	*10*	*12*	*8*	*10*	*12*
New Era . .	2	1·26	0·58	0·33	11·9	120·9	100·7
,, . .	4	1·84	0·71	0·29	123·4	103·9	143·3
,, . .	6	2·37	0·82	0·35	122·3	184·1	118·4
,, . .	Control	2·45	0·91	0·38	212·6	322·0	311·6
Dr. S. Up. . .	2	1·02	0·31	0·24	9·4	26·7	25·3
,, . .	4	1·45	0·93	0·16	12·7	37·7	24·5
,, . .	6	3·24	1·72	0·50	49·3	79·3	95·1
,, . .	Control	3·59	1·67	0·57	38·0	200·3	122·1
Local White .	2	2·99	2·38	1·81	0	0	13·3
,, .	4	2·99	2·92	1·62	0	0	10·3
,, .	6	3·17	3·11	2·32	0	0	18·5
,, .	Control	3·02	3·27	2·64	0	0·5	17·8
Least significant difference ($P = 0·05$)		0·56	0·35	0·12	39·2	58·4	83·7

[1] Mean of four samples each of twenty plants.

TABLE 5. *Effect of Time of Infection by Cowpea TMV on the Leaf Area and yield of Dr. Saunders's Upright Variety of Cowpea*[1]

Age of plants at time of inoculation (wks.)	*Leaf area (sq. m.)*			*Fresh weight of pods (gm.)*		
	Time of sampling (wks.)					
	8	*10*	*12*	*8*	*10*	*12*
2	1·15	0·60	0·42	46·5	47·3	28·3
4	1·69	1·19	0·95	149·1	89·5	89·4
6	2·12	1·25	1·08	191·8	108·4	101·6
Control	2·57	1·73	1·18	240·3	122·9	107·8
Least significant difference ($P = 0·05$)	0·54	0·48	0·13	23·9	16·3	18·2

[1] Each figure is the mean of four samples each of twenty plants.

Discussion and Conclusions

The experiments showed that cowpea yellow-mosaic virus can cause severe damage to the cowpea crop. The number of flowers and pods was reduced as a result of infection. Leaf area was also reduced and it might be expected that the photo-synthetic activity of the chlorotic leaves was lower. However, there was a compensating factor in that the ratio of yield per pod to pod number was greater in plants infected with cowpea yellow-mosaic virus than in healthy plants. Infection with cowpea tobacco-mosaic virus reduced the yield of cowpea to a lesser degree.

Time of infection with either virus was an important factor and, as expected, late infections had less effect on yield than early ones. However, even with infections as late as 6 weeks after planting, i.e. at a time

when the plants were beginning to flower, both viruses produced significant reductions in leaf area and numbers of flowers and pods. It is of interest that the local white variety was much less affected by infection with cowpea yellow-mosaic virus than either of the introduced varieties and it may well be that the breeder will be able to find a source of resistance to this virus in indigenous Nigerian varieties of cowpea.

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SIZE, SHAPE, AND NUMBER OF PLOTS FOR FIELD EXPERIMENTS WITH TEA

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Summary

The data collected from a series of plots of different sizes and shapes containing tea bushes of five different clones and all receiving similar treatments have given some very useful information.

Different clones can react differently to environmental conditions and hence the plot variances for different clones may vary.

Error was greatly reduced by increasing plot size from 9 to 36 bushes, but by further doubling the plot size the error was reduced by only 1 per cent., which is unimportant.

Narrow long plots were better than square plots.

A table has been presented to help in deciding the number of replications required in tea experiments. For this purpose knowledge of the nature and variability of the tea plants used is helpful, and one should also consider what treatment-mean differences are acceptable.

It has been further shown that oblong plots, with a length of at least 1½ times the breadth, have much less error than square ones. Optimum plot size appears to be in the region of 30 to 45 bushes.

Proper selection of the plants used for experimentation is of extreme importance and the difference between clones can be very variable. Used judiciously, reasonably uniform commercial tea raised from seed may be a better medium for some experiments than clonal plants.

TEA culture is perhaps the largest single agricultural enterprise of its kind in the world, in terms of acreage covered, labour employed, and financial turnover. The application of science to the tea industry has greatly increased during the past decade, bringing with it the need for a sound basis upon which to build a system of accurate and valid field experimentation.

PART I

The field experiment from which most of the data in the first part of this paper has been drawn was not laid out specifically as a uniformity trial, but bearing in mind all the technical difficulties involved in uniformity trials [1] it is felt that these data, supported by those in the second part, may prove a useful guide to those who conduct field experiments with tea.

Experimental Area

The experimental grounds are situated in the middle of the Brahmaputra Valley, at an altitude of about 300 feet. The soil is a rather poor light alluvium. Annual rainfall is about 80 in., of which about 60 in. may fall in the four monsoon months June–October, the remainder being fairly well distributed. In this first experiment the tea was unshaded.

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Experimental Design

Tea plants raised by cuttings from five clones were square planted 4 ft. 6 in. apart in 1951, in a Latin Square layout, each plot having 225 bushes (15×15). Subsequently, for reasons which do not affect the present data, one entire clone and one outside column of the Latin Square were discarded, leaving four replications of the remaining four clones. The experiment planned for this area involved splitting the clonal plots four times, giving 16 subplots each of 9 bushes (3×3) within each clonal sub-block of 144 bushes. The balance of 81 bushes was in the guard lines around the plots.

The units dealt with in the first experiment were thus made up as follows:

The ultimate unit was the individual tea bush and as 4 clones were used, virtually only 4 tea bushes were used, each suitably propagated to make up the requirements of the experimental layout. Methods of propagation, planting, pruning, and plucking were identical for each clone and each plot, and there were no apparent sources of error to be considered in these respects. It is permissible therefore to consider any significant differences between plots of different sizes and shapes as due to such actual differences. Differences in the behaviour of clones, where they occur, must be attributed to the reactions of different clones to the environment as it occurs under the conditions of this experiment. A sub-plot unit of 9 bushes (3×3) is a plot for the purposes of all calculations relating to plot-size of 9 bushes. Likewise all other sizes and shapes of plot made up of the various possible arrangements of a number of 9-bush units are regarded as plots in their respective calculations. The combinations include plots of 18 bushes (6×3), 36 bushes (12×3), 36 bushes (6×6), and 72 bushes (12×6). Further details of this grouping are given subsequently under the heading 'Grouping of sub-plots'.

It is customary at this Station to take preliminary yields from experiments during the year prior to the first application of treatments, all subsequent yields being submitted to analysis of covariance. This serves to increase the precision of the experiment. In this case, preliminary yield figures, relating to the weight of fresh green shoots plucked from each plot on a weekly round, were obtained from the 1955 plucking season.

Consequently, at the end of 1955, there were available a series of crop-yield figures for a group of 256 small, square plots, each of 9 bushes (3×3), corresponding to the smallest plots under consideration.

The layout of a sub-block is shown in Fig. 1.

Any sub-block consists of 225 bushes (including guard lines) all of the same clone. Any whole block consists of 4 replications of each sub-block, where each replication is a different clone.

One whole plot consists of the sub-plots numbered 1 to 8 in Fig. 1, and is therefore of 72 bushes (12×6), and this coincides with the largest combined-plot size as described above.

The various ways in which the plots were grouped and the data analysed are described below. All figures quoted are in ounces of green leaf plucked during the 1955 season.

Determination of Variation between Clones and Within Clonal Plots

To calculate the variation between clones, the total weight of leaf harvested from sub-blocks (144 bushes) was used. The yields are given in Table 1.

The analysis of variance, with three degrees of freedom between clones, indicated a very highly significant difference ($P < 0{\cdot}001$) between clones.

To calculate the coefficient of variation of each clonal plot, individual

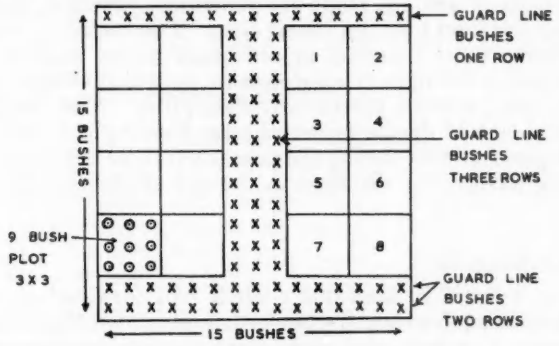

FIG. 1

TABLE 1. *Yields in Ounces of Green Leaf—1955*

Sub-blocks	*Clones*				
	1	*2*	*3*	*4*	*Total*
I .	1,440	2,685	1,069	1,717	6,911
II .	1,535	2,113	865	1,678	6,191
III .	1,621	2,642	1,215	2,011	7,489
IV .	1,777	2,614	1,397	2,383	8,171
Total . .	6,373	10,054	4,546	7,789	28,762

General mean—1,798. Least significant difference between marginal totals—1,053.

figures of each 9-bush sub-plot were used. There were 16 sub-plots within each sub-block, and 4 sub-blocks within each clone, giving 3 degrees of freedom between sub-blocks and 60 for error (within sub-blocks).

The resulting coefficients of variation were:

Clone 1	16·22 per cent.	Clone 3	27·24 per cent.
Clone 2	16·72 ,,	Clone 4	17·52 ,,

Clone 1 is seen to exhibit the least plot variance, and Clone 3 the most; there is probably no real difference between clones 1, 2, and 4. (Plots of Clone 3 were shown subsequently to have a higher coefficient of variation than similar plots of a well-known commercial population of tea.)

To calculate the variation within clones, and to determine if there was any difference between clones in the 'within clone' variation, Bartlett's test of homogeneity was applied, with the result that clones were shown to differ highly significantly in their means and in their variances ($P < 0.01$).

Subsequent analyses to determine the optimum plot size and shape (within the limits of this experiment) were carried out on two of the clones only, Clone 1 (C.V. 16·22) and Clone 3 (C.V. 27·34), i.e. those exhibiting the lowest and the highest coefficients of variation respectively.

As the plants of any one clone are genetically identical, there can be no genetical variation between clonal plots. The variations observed in this experiment must therefore be attributed to the reaction of clonal plants to small differences in environment, to which clones, because of their uniformity, may be particularly susceptible. Also, in Clone 3, a higher percentage of deaths occurred after planting out, and more infilling took place, so that during the year when these data were collected (1955) there was greater variation in the age of plants within plots of Clone 3.

Grouping of Sub-plots

From Fig. 1 it will be seen that a whole plot consisted of 72 bushes, divided into 8 sub-plots each of 9 bushes, numbered in Fig. 1 from 1 to 8. For purposes of analysis, sub-plots were grouped together in various ways to give different sizes and shapes of plot. The chosen combinations were:

A. Plot size $3 \times 3 = 9$ bushes, from sub-plot 1 and all similar sub-plots. Thus, with 8 sub-plots in each whole plot, and 8 whole plots of each clone, there were 64 observations for the square plot of 9 bushes.

B. Plot size $6 \times 3 = 18$ bushes, from pairs of sub-plots, i.e. 1 and 3, 2 and 4, 5 and 7, 6 and 8, making 4 observations in each whole plot, and 32 observations for each clone.

C. Plot size of $12 \times 3 = 36$ bushes, from sub-plots 1, 3, 5, and 7 combined, and 2, 4, 6, and 8 combined, a total of 16 observations for each clone.

D. Plot size of $6 \times 6 = 36$ bushes, from sub-plots 1, 2, 3, and 4 combined, and 5, 6, 7, and 8 combined, a total of 16 observations for each clone.

E. Plot size of $12 \times 6 = 72$ bushes, comprising each whole plot, making a total of 8 observations for each clone.

Analysis of Data from Combined Sub-plots of Clone 1

Total yield figures for combined sub-plots were used to calculate the coefficient of variation for each plot size. It was considered that as significant differences were found between clones, the coefficient of variation would give a more legitimate comparison than error variances, as it takes into consideration both the means and the variances. Results were as follows (Table 2):

TABLE 2. *Coefficients of Variation for different Plot Sizes and Shapes, for Clone 1*

Plot size and shape (numbers of bushes)	*Analysis of variance. Degrees of freedom*		*Coefficient of variation* %
	Sub-blocks	*Error*	
A. 3×3 .	3	60	16·22
B. 6×3 .	3	28	11·30
C. 12×3 .	3	12	6·33
D. 6×6 .	3	12	10·05
E. 12×6 .	3	4	5·62

Analysis of Data from Combined Sub-blocks of Clone 3

(calculated as for Clone I)

A.	Plot size 3×3	C. of V.	27·34 per cent.
B.	Plot size 6×3	,,	22·86 ,,
C.	Plot size 12×3	,,	18·02 ,,
D.	Plot size 6×6	,,	20·25 ,,
E.	Plot size 12×6	,,	16·65 ,,

In experiments of this sort it is inevitable that differences in plot size are associated with differences in plot shape, although in this instance

TABLE 3. *Effect of Plot Shape on Coefficient of Variation*

Size of plot (bushes)	*Shape of plot (bushes)*	*Coefficient of variation*	
		Clone 1	*Clone 3*
36	6×6 square	10·05	20·25
36	12×3 oblong	6·35	18·02

oblong and square plots each containing 36 bushes can be compared directly.

Variation of plot shape with a constant plot size is seen from Table 3 to be an important factor, affecting the coefficient of variation.

Thus, if plot size was kept constant, in this case at 36 bushes, the oblong plots (12×3) had a much lower coefficient of variation than the square plots (6×6). This is a confirmation of previous findings by other experimenters, particularly in regard to annual crops [2], and is further confirmed by the data presented in the second part of this paper.

The effect of varying plot size can be seen from Fig. 2. It should be noted that the 9-bush plots were square, but the curves indicate that the results might not have been greatly different if they had been rectangular. The position of the 36-bush square plots is indicated also.

Fig. 2 shows that the error was greatly reduced by increasing plot size from 9 to 36 bushes, but thereafter very little further reduction was achieved. Obviously it would not be practicable to double plot size in

order to reduce the error by 1 per cent. Far better results could be achieved from the smaller plot size, with greater replication if necessary.

It is also seen from Fig. 2 that, due to the very high degree of variation between plots of Clone 3, a plot size of 72 bushes with this clone exhibited greater error than a plot size of only 9 bushes with Clone 1.

In another experiment at this Station, using a commercial population of tea (raised from seedlings) and employing 32 bushes per plot (4×8),

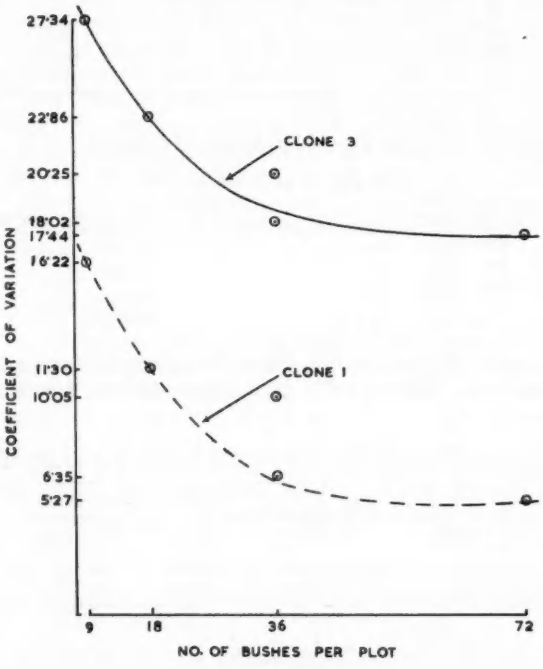

FIG. 2

the coefficient of variation of such plots was found to be only 8·70 per cent. There is no statistical relationship between these two experiments, other than that they were conducted at the same Station. Further details drawn from many other field experiments at this Station and on commercial gardens are presented in the second part of this paper.

The above data are condensed in tabular form in Table 4.

From this table it is seen that the commercial tea, raised from seedlings, in a plot of 32 (4×8) bushes, compared very favourably with Clone 1, and would be much superior to Clone 3, as experimental material under these conditions.

It would appear, therefore, that some clonal material is not necessarily better than some seedling material for some experimental purposes. This is discussed more fully later.

Number of Replications required in Tea Experiments

From the data available at this Station, where over a hundred separate agricultural experiments on tea have been carried out in the last thirty years, the following statement, in conjunction with the above data concerning size, shape, and variability of plots, should provide the experimenter with almost all the prior information necessary to design and lay out a suitably accurate field experiment with tea, under conditions similar to those prevailing in this Station.

One should know first of all the nature and extent of variability in the material one is using, be it clonal (variability as measured by reaction to environment) or seedling material. It has already been shown above how greatly two clones may differ in their sensitiveness to environment. The

TABLE 4. *Coefficients of Variation for Different Material in Different Plot Sizes (per cent.)*

Bushes per plot	*Clone 1*	*Clone 3*	*Commercial tea*
9	16·22	27·34	..
18	11·30	22·86	..
32	..	..	8·70
36	6·35	18·02	..
72	5·27	17·44	..

fact that one clone did not suit its environment as well as the other three and had to be more heavily infilled is a measure of this sensitivity. It is assumed that the conditions of the environment must have varied near the critical survival range for this clone, which, by reason of the latter's genetical uniformity, is narrow. One should also consider what difference one is prepared to accept between treatment means. This will vary with the nature of the treatment, either for economic, practical, or other reasons.

With these two items of information decided upon, the number of replications may be decided simply by reference to a suitable table, such as Table 5 below [3].

Thus, for example, if one proposes to conduct a trial using Clone 3 (known coefficient of variation listed in Table 3), in order to show differences of 15 per cent. as significant at the 5 per cent. level, it would be necessary only to refer to such a table and read off the replications required in the appropriate column. Conducting an experiment with Clone 1 would require a considerably smaller number of replications, using the same plot size and shape, than Clone 3.

Conducting the same experiment with the commercial tea referred to in Table 4 would require approximately only the same number of replications as Clone 1, to be highly satisfactory under the conditions specified, and certainly less replications than Clone 3.

TABLE 5. *Number of Replications Required for a Given Probability of obtaining a Significant Result (After Cochran and Cox [3])*

(For randomized-block layouts with four treatments)

Significant difference reqd. as percentage of mean	*True standard error per unit as % of mean (C. of V.)*															
	2	3	4	5	6	7	8	9	10	11	12	14	16	18	20
5	4	7	11	17	24	32	41								
	5	9	15	22	31	42									
	7	14	24	38											
10	2	3	4	5	7	9	11	14	17	20	24	32	41		
	2	3	5	7	9	12	15	18	22	27	31	42			
	3	5	7	11	14	19	24	30	37	45					
15	2	2	3	3	4	5	6	7	8	10	11	15	19	24	29
	2	2	3	4	5	6	7	9	11	13	15	19	25	31	39
	3	3	4	6	7	9	12	14	17	21	24	33	42		
20	2	2	2	3	3	3	4	5	5	6	7	9	11	14	17
	2	2	2	3	3	4	5	6	7	8	9	12	15	18	22
	2	3	3	4	5	6	7	9	11	12	14	19	24	30	37
25	2	2	2	2	2	3	3	3	4	4	5	6	7	9	11
	2	2	2	2	3	3	4	4	5	5	6	8	10	12	15
	2	2	3	3	4	5	5	6	7	9	10	13	16	20	24
30	2	2	2	2	2	2	3	3	3	4	4	5	6	7	8
	2	2	2	2	2	3	3	3	4	4	5	6	7	8	11
	2	2	3	3	3	4	4	5	6	6	7	9	12	14	17

Upper figure: test of significance at 5 per cent. level, probability 80 per cent.
Middle figure: test of significance at 5 per cent. level, probability 90 per cent.
Lower figure: test of significance at 1 per cent. level, probability 95 per cent.

No entries are given where more than fifty replications are required.

PART II

The results of eighteen field experiments are presented below; they fall into the following categories (Table 6).

TABLE 6. *Details of Experiments*

	No. of expts. in commercial gardens	*No. of expts. at Tocklai*
Square plots . .	4	6
Rectangular plots .	2	6
Total . .	6	12

Many of the early experiments were laid out in sections of mature tea. That is to say, the tea area was not planted out to suit the particular experiment, but the experiment was fitted into the existing area in the most convenient manner. For this reason plot sizes and shapes have varied over a wide range. In some cases where the plot shape has been described

as square, this does not necessarily mean geometrically square. Where the length of a plot is more than 1½ times the breadth its shape is described as rectangular, and where less than 1½ times the breadth, as square. The actual number of bushes along the length and breadth of plots is stated in each case.

The following comparisons are drawn and discussed below.

1. Square versus rectangular plots, within the limits noted above (Tables 7 and 8).
2. Increasing and decreasing plot size (Tables 7 and 8).
3. Experiments at Tocklai versus experiments in commercial gardens (Table 9).

TABLE 7. *Coefficient of Variation of Plots whose Length is less than 1½ times their Breadth* (*i.e.* 'SQUARE')

Expt. no.	*Number of bushes per plot*	*Bush arrangement*	*Coefficient of variation %*
1	30	5×6	19·5
2	48	6×8	8·2
3	72	8×9	10·3
4	80	8×10	12·6
5	90	9×10	10·7
6	100	10×10	5·4
		Mean C. of V.	11·1

TABLE 8. *Coefficient of Variation of Plots whose Length is more than 1½ times their Breadth* (*i.e.* 'RECTANGULAR')

Expt. no.	*Number of bushes per plot*	*Bush arrangement*	*Coefficient of variation %*
7	28	4×7	8·8
8	36	4×9	9·0
9	45	5×9	6·5
10	54	6×9	7·8
11	84	7×12	6·3
12	96	8×12	6·9
		Mean C. of V.	7·5

All the experiments to which Tables 7 and 8 refer were conducted by the Experiment Station. Those in Table 7 cover approximately the same range of plot size as those in Table 8, viz. 30–100 and 28–96 respectively.

In Table 7 maximum C. of V. recorded is 19·5 per cent. and the minimum 5·4 per cent. for 'square' plots, whilst in Table 8 the maximum is 9·0 per cent. and minimum 6·3 per cent. for 'rectangular' plots. The respective mean coefficients of variation are 11·1 and 7·5 per cent.

This corroborates Table 4 in that it indicates much lower errors using rectangular than with square plots. The reduction in error with increasing plot size is very slight for the rectangular plots, and much more marked for the square ones.

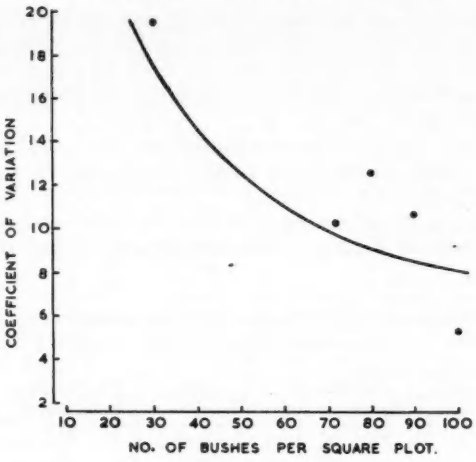

FIG. 3

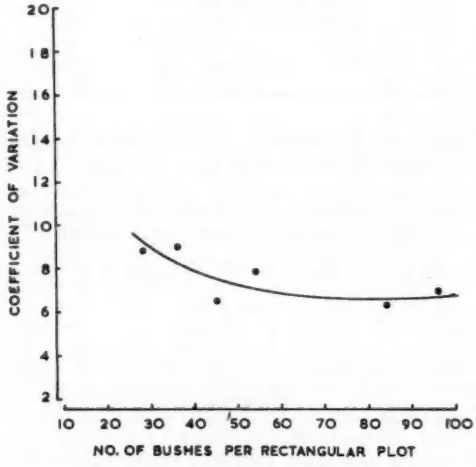

FIG. 4

The effect of increasing plot size is more clearly shown in Figs. 3 and 4. Not only were rectangular plots preferable to square ones, but with them the experimenter can also reasonably be justified in using smaller plots. In all cases cited, for rectangular plots the C. of V. was below 10 per cent. even with a plot size of as small as 28 bushes.

Garden Experiments

By 'garden experiments' is meant those experiments which are conducted under commercial conditions on a tea garden as opposed to those

conducted at the Experiment Station. As would be expected they are not generally as accurate as those conducted with the experienced staff and labour available at an Experiment Station, and error is correspondingly higher. In spite of this, and the small number of samples taken for illustration, the same general trends are in evidence, as seen from Table 9 below. It will be noted that one of the rectangular plots is of extreme shape.

From Table 9 it is seen that the error was generally higher than with similar plot sizes under Experiment Station conditions. Also, square plots exhibited higher error than rectangular plots. Regarding increasing plot size there is not sufficient evidence in Table 9 to justify drawing any

TABLE 9. *Coefficients of Variation for Plots in Garden Experiments*

	No. of bushes per plot	*Bush arrangement*	*C. of V.*	*Mean C. of V.*
Rectangular .	61	1×61	13·0	
	76	4×19	10·2	11·6
Square . .	80	8×10	10·7	
	81	9×9	12·4	
	121	11×11	14·4	12·4
	225	15×15	12·2	

conclusion, but there is no reason to suppose that the conclusions drawn from Experiment Station figures should not apply to garden conditions, bearing in mind the generally higher error, all other things being equal.

Conclusions

In order that valuable information may not be lost from future experiments through insufficient replication, or inappropriate plot size or shape, the writers have endeavoured to put forward statistical evidence to show the various optima found to be of importance in tea experimentation at this Station, and on tea gardens throughout Assam.

It has been shown that, irrespective of the variability of the material, oblong plots, with a length of at least 1½ times the breadth, are better than square ones from the point of view of minimizing the error.

Optimum plot size would appear to be in the region of 30–45 bushes. Apart from statistical reasons, it would be neither desirable nor practicable to reduce plot size much below this, even with greater replication. The main reason for this is the amount of crop which one may expect to harvest from a certain number of bushes on any plucking round. When the weight of the crop becomes too small, accuracy of weighing becomes questionable; from 30 mature tea bushes only a few ounces of leaf each week would be harvested.

On the other hand, it might sometimes be desirable to increase plot size above 45 bushes, as, for instance, perhaps with trials involving commercial irrigation equipment. Even using mature shade trees in shade-density experiments, a plot size of 30 bushes, plus the necessary guard lines, has been found quite adequate.

Selection of material for experiment is a factor of extreme importance, and one which is often overlooked, or at least minimized. It has been shown in previous publications from this Station [4] that different sources of material respond differently to such treatments as manuring, shade, &c., and this, coupled with plot variability, should always be borne in mind.

It would appear particularly important not to place too much reliance on the fact that one is using 'Clonal material', as this has been shown to be capable of producing plots with a very high standard error. Reasonably uniform commercial tea raised from seedlings, and utilized with consideration for the optimum plot size and shape, would perhaps be a more suitable medium for some experiments such as manurial trials than clonal material. The latter is likely to be more specific in its requirements than a population raised from seedlings, and information obtained would not necessarily be as widely applicable.

Decision as to the number of replications required can now be made with some knowledge of one's material, and reference to Table 5.

Acknowledgements. Thanks are due to Mr. W. J. Ridgman of the School of Agriculture, Cambridge University, for suggestions on the use of the large amount of data available from various experiments conducted at this Station.

To Mr. B. N. Phukan and Mr. J. C. Bordoloi, computors at the Tocklai Experimental Station, for their part in the analysis of data.

To the Indian Tea Association, and the Director, Tocklai Experimental Station, for permission to publish this work.

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THE EFFECT OF GAMMA BHC ON THE GROWTH OF RICE SEEDLINGS

E. H. ROBERTS

(*West African Rice Research Station, Rokupr, Sierra Leone*)

WITH PLATE 2

Summary

When rice seed was stored in contact with dressings containing BHC, the seed accumulated gamma BHC (and probably other isomers if present). After 2 months' storage, deformities appeared on germination, and after 9 months these deformities reached a level of severity which was equivalent to growing undressed seed in solutions containing between 29·1 and 291 p.p.m. gamma BHC. The percentage germination was not affected. These results are discussed in relation to other work on the effects of gamma BHC on plant growth.

On several occasions during the last few years it has been noticed that a number of rice seed samples sent to the West African Rice Research Station, Sierra Leone, have failed to germinate. Usually, these samples were still within the normal period of viability for rice seed stored in the tropics (i.e. less than a year old). In order to comply with international phytosanitary regulations, it is necessary either to fumigate or dress seeds for exportation, against pests and diseases. One of the factors which it was suspected might be causing loss of viability was the use of dressings which are toxic to rice seeds. The experiments which are described here were carried out during the course of investigating the toxicity of some of the more common seed dressings, particularly gamma BHC which is the active insecticidal principle of a number of the more widely used seed dressings.

Experimental Work

A preliminary experiment was undertaken to find out whether three different seed dressings used singly or in combination affect the viability of rice seed. The dressings used were Agrosan GN (an organo-mercurial fungicide containing 1 per cent. of mercury), Agrocide Dispersable Powder (an insecticide containing 6·5 per cent. gamma BHC), and Didimac Dust (an insecticide containing 5 per cent. technical DDT). A good-quality sample of the rice variety 'Lead' was sun-dried after harvest to 11 per cent. moisture content and divided into six aliquots of 8 oz. which were treated with the following dressings: (1) control—not dressed, (2) 1 gm. Agrosan GN, (3) 1 gm. Agrocide, (4) 1 gm. Didimac, (5) 1 gm. Agrosan GN and 1 gm. Agrocide, (6) 1 gm. Agrosan GN and 1 gm. Didimac. The seeds were then stored in unsealed tins in the laboratory (average temperature approximately 27° C.). Samples of 100 grains were taken from each tin at approximately monthly intervals and germination tests were carried out on moistened filter papers in petri dishes incubated at 32° C. The experiment was continued for 9 months and during this period the moisture content of the seeds

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rose to 14 per cent.; this represented typical local storage conditions. None of the treatments had any effect on percentage germination of seeds. However, the tests carried out 2 months after the seeds were dressed showed that the growth of seedlings immediately following germination had been adversely affected by storage with any dressing which included Agrocide. The main symptoms were extremely stunted roots and swollen coleoptiles. The symptoms became more marked with increase in the storage period. It was shown, however, by an experiment in which the stunted seedlings were transplanted to soil in plant pots soon after germination, that the seedlings were capable of overcoming these deformities and their later growth was comparable with that of the control plants. In this connexion it is interesting to note that it has been shown [1] that some of the BHC taken up by wheat seedlings disappears, probably by volatilization of the BHC or some product formed from it.

It was decided to extend these investigations by germinating and growing seedlings in contact with solutions containing known concentrations of the pure gamma isomer. The source of the gamma BHC used was Gammalin 20 (Plant Protection Ltd.). This is an approximately 20 per cent. gamma BHC solution in organic solvents. Messrs. Plant Protection Ltd. kindly supplied samples of their solvents, and it was shown by experiment that at the concentrations of Gammalin 20 used in these investigations these solvents had no detectable effect on the growth of rice seedlings. The technique used in these experiments was as follows: seeds were germinated in the apparatus illustrated in Fig. 1. One seed was placed in each flask, and ten replicates were used for each treatment. Solutions of Gammalin 20 were made up in distilled water and 100 ml. placed in each flask. The flasks were put in an incubator at $32 \pm 1°$ C. with the outer door removed so that the seedlings were subjected to diffuse daylight. Each test normally lasted 7 days. At the end of this period photographic records were made together with observations on any obvious morphological deviation of the treated from the control seedlings grown in distilled water.

The effects of solutions containing from 10^{-6} molar (0·291 p.p.m.) to 10^{-3} molar (291 p.p.m.) gamma BHC were investigated. During the period of the experiment the solution containing 10^{-6} molar had no visible effect, but the higher concentrations showed an increasing amount of root inhibition with increase in concentration. At 10^{-3} molar the shoots were also severely inhibited and the coleoptiles were swollen (Plate 2, Fig. 2). The severity of the symptoms produced in the storage experiments after 9 months was intermediate between that produced by 10^{-3} and 10^{-4} molar gamma BHC. These experiments thus strongly suggest that when rice is stored with Agrocide, BHC accumulates in the seed and that this accumulation continues for at least 9 months, when the symptoms become more severe than are obtained by germinating undressed seed in 10^{-4} molar gamma BHC.

Agrocide Dispersable Powder which was used in the preliminary storage experiment is a product which contains technical BHC, and therefore only part of the BHC present is the gamma isomer. Unpublished work (J. F. H. Cronshey, private communication) on the

other isomers has shown that they have almost a comparable phytotoxic effect to that of the gamma isomer; the effect of the Agrocide used would be equivalent to a pure preparation containing 50 per cent. of the gamma isomer. From the published recommended doses for seed dressings containing the gamma isomer, this means that, considering all the isomers present, about twice the recommended maximum dose was used in the storage experiment. If it is considered that this margin is

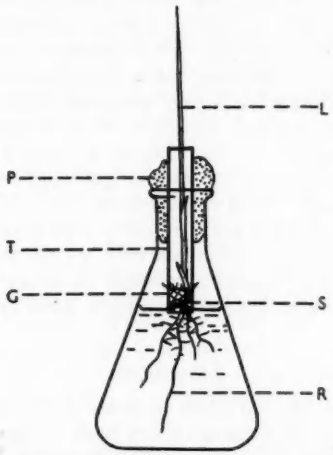

FIG. 1. Diagram of the apparatus used to test the effects of gamma BHC on the growth of rice seedlings. The apparatus consists of a 100 ml. conical flask containing 100 ml. of the solution to be tested; the seed (S) is held at the surface of the solution in a 10 mm.-bore glass tube (T) the end of which is covered with a small piece of cotton gauze (G) tied on with cotton; the tube is held in position by a cotton-wool plug (P). The diagram illustrates a typical control seedling after 7 days' growth; R = roots; L = second leaf.

necessary as a reasonable safety factor, then these experiments suggest that BHC should not be used on rice seed which is to be stored for any length of time, though it is quite safe to use providing the seed is dressed only a short time before sowing. In the storage experiment the abnormalities began to appear after 2 months. If, however, the seed had been damp, judging from unpublished work on other cereals (J. F. H. Cronshey, private communication), it is likely that the abnormalities would have appeared after a shorter storage period. Liquid formulations, having a greater penetration, would also probably have resulted in more severe symptoms according to the same unpublished work.

Some of the symptoms produced by BHC in the present experiments suggested that it might be behaving in some way similarly to substances with auxin activity. For instance, one of the main symptoms shown by

substances with auxin activity is the inhibition of root growth at molar concentrations of the same order as the concentrations of gamma BHC which had this effect in the present experiments. It was shown that the inhibition of root growth is not a nonspecific effect produced by any substance present in toxic concentrations, by an experiment in which the effects of concentrations of sodium chloride (10^{-1} to 10^{-4} molar) and methyl alcohol (1 to 10^{-4} molar) were tested on rice seedlings. It was found that at concentrations which markedly inhibited growth—10^{-1} molar sodium chloride and molar methyl alcohol—the inhibitory effect was shown almost equally by both roots and shoots; concentrations less than these had practically no effect. On the basis of growth stimulations of parsnip and mangold seedling roots with very low concentrations of chlorinated hydrocarbons including gamma BHC, MacLagan [2] also made a tentative suggestion that gamma BHC might behave in a similar way to auxins. A comparison was therefore made between the effects of gamma BHC and a number of substances with auxin activity, on the growth of rice seedlings. The results with the substances having auxin activity [3] showed that it is very unlikely that gamma BHC behaves as an auxin, because all the substances with auxin activity, when used at suitable concentrations, caused a reversal of coleoptile geotropism and the production of an epicotyl; these effects were not shown by gamma BHC.

Discussion

Previous work has shown that gamma BHC has the property of accumulating in seeds (for recent work and summary of literature see Bradbury and Whitaker [1]) and it has also been observed that under certain conditions it can affect the growth of seedlings. Abnormalities similar to those obtained in the present experiments have previously been found in wheat, barley, and oats which have been dressed with gamma BHC [1, 4]; Thomson [4] described these symptoms as 'thickened coleoptile and short peg-like roots'. Thomson made a special investigation into the effects of a dressing containing 20 per cent. gamma BHC and 1 per cent. mercury applied at the rate of 2 oz. per bushel (assuming an 84 lb. bushel this gives a ratio of 1:3,360 gamma BHC to seed) on the germination and growth of oat seedlings. He found that abnormal seedlings were produced and that their number tended to increase the longer the seed was stored after dusting, but even after a year the effect under good storage conditions, although significant, was still of no practical importance. His results indicated that the lemmata and paleæ had a protective influence and the harmful effect was almost, if not completely, confined to the dehusked seed. In this way oats would appear to differ from rice as the present experiments were carried out entirely on seed which was not dehusked. It is not conclusive from Thomson's results that gamma BHC was toxic to oat seeds, as the organo-mercurial compound was also present, but he states that it has been noticed at official seed-testing stations that dressings containing a mixture of gamma BHC with an organo-mercurial compound cause a greater number of abnormalities than a dressing containing an organo-

mercurial compound alone. Srivasta [5] found that seed dressings of from 3 to 5 oz. of 25 per cent. Lindane to 100 lb. wheat seed (i.e. from 1:2,133 to 1:1,280 gamma BHC to seed) lowered the germination to approximately 78 per cent. compared with 97 per cent. for untreated seed after 4 months' storage, but root growth was unaffected.

The present storage experiment using Agrocide showed that it was not merely the BHC dust on the seed coats being carried over to the germination dishes which caused abnormalities, because no abnormalities appeared for 2 months, and thereafter the symptoms became more severe with time. These facts suggest that the BHC which caused most of the damage in this storage experiment was the fraction of BHC which was absorbed by the seed prior to the tests. It has been reported [6] that after treatment with BHC, seeds are more likely to show abnormalities in germination tests when carried out on filter paper or sand than when carried out in soil. This is presumably because some of the BHC which has not already been absorbed by the seed is absorbed by the soil and is therefore unable to affect the seed. It is likely then that in the present storage experiment the severity of the symptoms at any stage after storage commenced would have been less if the seed had been sown in soil. However, in rice more than in other cereals, it is important to consider abnormalities which are likely to develop when the seed is germinated without benefit of contact with the soil, because in many regions under certain conditions it is the normal practice to pregerminate the seed for several days before sowing. The conditions under which rice seed is pregerminated would approximate more closely to the standard germination-test methods than with germination in the soil.

Lilly and Fahey [7] have shown that when heavy dressings of gamma BHC are applied to the soil, measureable quantities of gamma BHC could be detected in seeds of various crops for at least 3 years after application (rice was not included in these experiments). With an application of 50 lb./acre, concentrations within the seeds varied from 0·41 to 1·31 p.p.m. Germination of all seeds was unaffected. The concentrations found in the seeds by Lilly and Fahey are not very different from the concentrations in the external solutions which cause root inhibition in rice seedlings (in the present experiments 10^{-5} molar or 2·91 p.p.m. gamma BHC reduced root growth to less than half that of the controls). It is not known what relation the concentration of the external solution bears to the concentration of gamma BHC within the seed in the present experiments. However, very heavy field dressings would appear to be quite safe for rice: Jordan [8] applied a dressing of 1 oz./square yard of Agrocide Dispersable Powder (equivalent to 19·7 lb./acre of gamma BHC or a much higher concentration of total BHC) to rice seedlings in the nursery and did not note any deleterious effects.

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Gammalin 20 and to the Director of Agriculture, Sierra Leone for allowing publication of this work.

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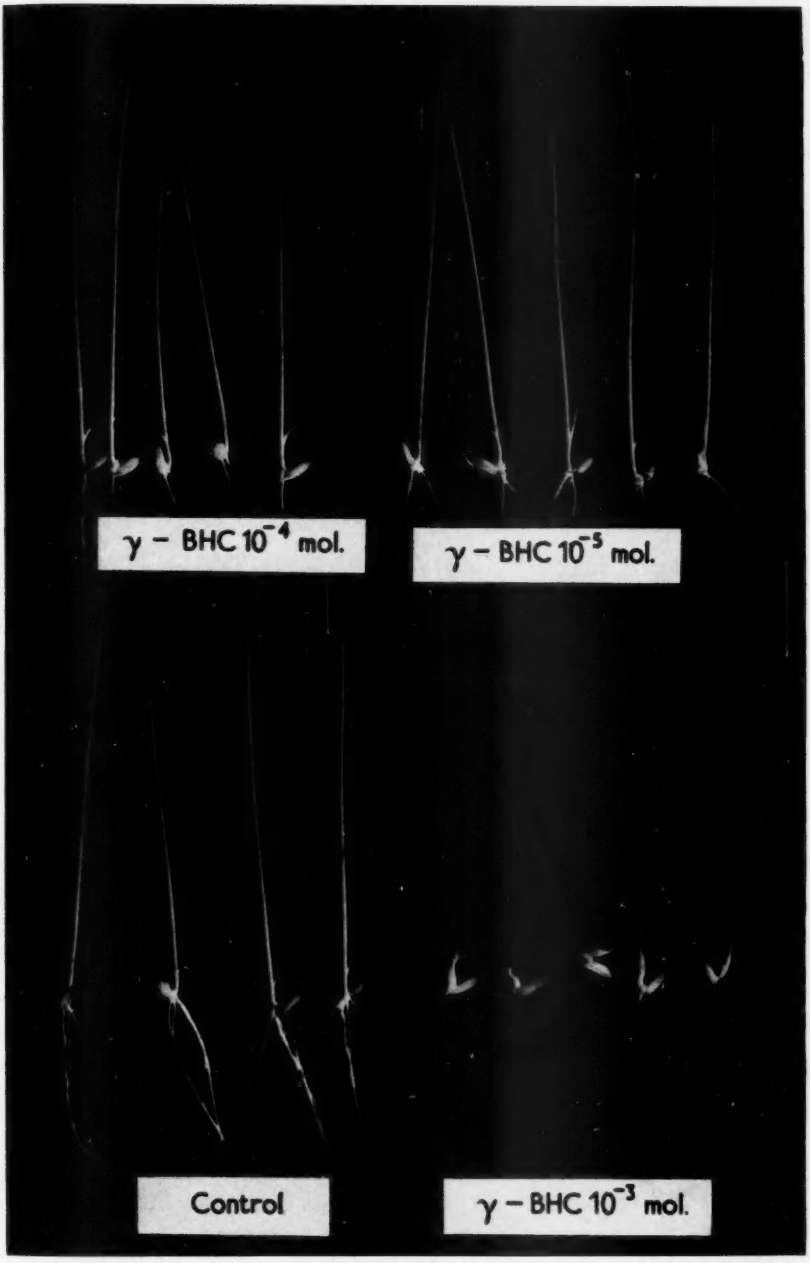

FIG. 2. Photograph of rice seedlings germinated and grown in water and in various concentrations of gamma BHC for 7 days.

THE EFFECT OF MOISTURE CONTENT ON THE GERMINATION AND GROWTH OF FUMIGATED MAIZE GRAIN

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Summary

The viability of stored maize was affected both by its moisture content and by fumigation with a mixture of carbon tetrachloride and ethylene dichloride. During the first 3 months of storage unfumigated grain at a moisture content of less than 13 per cent. maintained its viability. At higher moisture contents viability was not maintained, the rate of loss increasing with moisture content. The viability of fumigated grain was maintained for 3 months if its moisture content was below about 11 per cent.; above this level the rate of loss of viability was comparable with that for unfumigated grain above 13 per cent. moisture content.

Growth of unfumigated grain as measured by height or weight was unrelated to moisture content, but with fumigated grain there was a depression of growth increasing with moisture content over the range tested.

IT has been shown [1] that maize grain fumigated with a mixture of ethylene dichloride and carbon tetrachloride may not be suitable for planting. Fumigation appears to lower the growth rate of seedlings rather than to affect germination. Furthermore, it has been shown [1] that this depressive effect on growth, induced by the fumigant, is irreversible and varies with change of temperature. The part played by moisture content in determining the effect of fumigation on the germination and growth of maize is described below.

Materials and Methods

Maize grain (var. Trinidad) at a moisture content of 25 per cent., was slowly dried using a current of warm air, and samples were tested at regular intervals until the grain had reached a moisture content of 14 per cent. as measured by a Marconi meter. At this stage about 500 gm. of maize were placed in each of ten 2-lb. jars fitted with air-tight lids. This procedure was repeated at 13, 12, 11, and 10 per cent. moisture content. All the jars were left for a week at room temperature to reach equilibrium, and then a sample from each jar was tested for moisture content with a Marconi meter. Five of each set of ten jars were treated with a 1:1 mixture of ethylene dichloride and carbon tetrachloride at a rate of 0·7 c.c. per litre of total volume. The jars were immediately sealed and stored at room temperature (75–85° F.) for 3 months.

At the end of this period the jars were opened and the grain was tested for viability and its ability to produce healthy seedlings. The viability was determined by placing fifty seeds from each jar on moist filter paper

[1] Now in the Department of Botany, University of Queensland.

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in petri dishes. The numbers of grains germinating daily for 10 days were noted and those that had germinated were discarded. The ability of the grain to produce healthy seedlings was tested by planting ten grains from each jar in 8-inch pots filled with garden soil. The pots were set out at random in a 5×12 block in a glasshouse. Ten days from sowing the height of each plant was measured and the combined fresh weight of the plants in each pot was determined. The height of each plant was measured by drawing the leaves up vertically from the base and recording the distance between the soil and the highest leaf tip. The bulk fresh weight for each pot was determined after washing out the soil from each pot and drying the plants on absorbent paper.

Results

Germination

The number of grains germinating in samples of 250 is shown in Table 1. Each sample was made up of fifty grains taken from each of the five jars having the same moisture content and treatment.

TABLE 1. *Number of Seeds Germinating in Samples of 250*

% Moisture content	*Unfumigated*	*Fumigated*
14·7	226	212
14·1	223	217
13·2	245	230
12·2	245	241
11·0	245	245
10·6	245	248

An analysis of variance of these data revealed that both the moisture content of the grain and fumigation significantly ($P = 0{\cdot}01$) affected viability. These effects were apparently additive for there was no significant interaction between treatment and moisture content.

Though the overall viability of both the fumigated and unfumigated grain decreased during storage, the relationship between percentage viability and moisture content differed in the two series. With the unfumigated grain there was no loss of viability at moisture contents below about 13 per cent. With fumigated grain there was no loss of viability at moisture contents below about 11 per cent.

Seedling Height

The mean heights of seedlings raised from fumigated and unfumigated grain stored at different moisture contents are summarized in Table 2.

From this table it is evident that fumigation had an adverse effect on seedling growth and that the intensity of this effect increased with the moisture content at which the grain was stored. With one exception the differences in mean height observed were statistically significant.

TABLE 2. *Mean Seedling Heights for Fumigated and Unfumigated Grain stored at different Moisture Contents Ten Days from Sowing*

	Mean height ± S.E. (cm.)		
% Moisture content	*Unfumigated*	*Fumigated*	*Difference ± S.E.*
14·7	33·1 ± 0·8	18·9 ± 1·3	14·2 ± 1·5
14·1	31·4 ± 0·9	23·1 ± 1·1	8·3 ± 1·4
13·2	31·7 ± 0·9	24·9 ± 1·3	6·8 ± 1·6
12·2	30·2 ± 0·8	24·9 ± 1·3	5·3 ± 1·6
11·0	30·3 ± 0·6	32·3 ± 1·2	−2·0 ± 1·3
10·6	32·2 ± 0·8	26·2 ± 1·4	6·0 ± 1·6

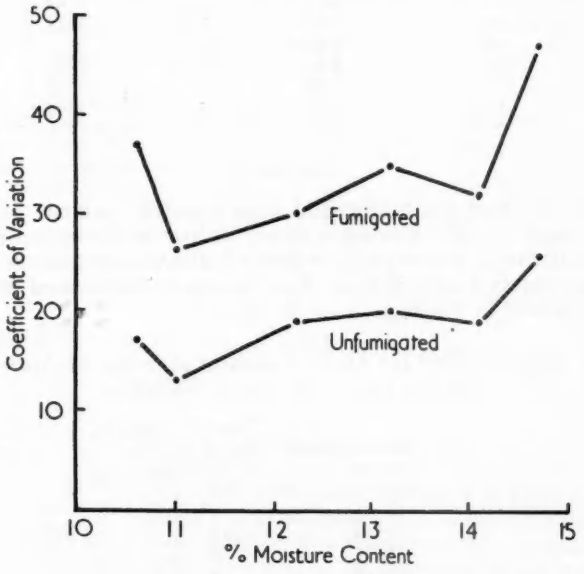

FIG. 1. The effect of fumigation on the coefficient of variation of height of plants grown from maize of different moisture content.

The mean heights of seedlings from unfumigated grain were not correlated with moisture content. In the fumigated grain the mean seedling heights were inversely proportional to the moisture content. The differences between the fumigated and unfumigated series were significant with one exception.

The seedlings from the fumigated grain showed more variation in height as well as being smaller than those from unfumigated grain. This variation in height also increased with increasing moisture content in both series (see Fig. 1).

Fresh Weight

The mean fresh weights of seedlings from treated and untreated grain stored at different moisture contents gave results similar to those for seedling height, as may be seen in Table 3. Since the height and fresh weight of the maize seedlings were closely correlated these results will not be discussed further.

TABLE 3. *Mean Fresh Weights of Seedlings from Fumigated and Unfumigated Grain stored at different Moisture Content Ten Days from Sowing*

	Mean fresh weight (gm.)		
% Moisture content	*Unfumigated*	*Fumigated*	*Difference*
14·7	5·67	3·17	2·50
14·1	5·19	3·84	1·35
13·2	5·45	4·00	1·45
12·2	5·21	5·00	0·21
11·0	5·18	5·23	−0·05
10·6	5·28	4·44	0·84

Discussion

It is known that grain stored at high moisture content will lose its viability more rapidly than grain stored at low moisture content. This has been confirmed above and also by a supplementary experiment using the maize variety Lagos White. The results of this second experiment are summarized in Table 4.

TABLE 4. *Time required for Maize Grain at different Moisture Contents to lose Half of its Initial Viability*

% Moisture content	*Time to lose half initial viability*
12–13	> 52 weeks
13–14	36 ,,
14–15	32 ,,
15–16	12 ,,
16–17	6 ,,
17–18	4 ,,

It is also known that when grain is exposed to the air it will tend to a moisture content which is in equilibrium with the humidity of the atmosphere. The relationship between the moisture content of three varieties of maize grain and the relative humidity of the atmosphere, is shown in Fig. 2. The three varieties were chosen because of their differing physical characteristics, Ikom White being a floury maize, Mexican I being a dent, and Haiti being a flint maize.

The relative humidity throughout the principal maize-growing areas of Nigeria is rarely less than 70 per cent. during the months of harvest and storage of the main crop. At harvest, maize has a moisture content of about 25 per cent. and it is clear from Fig. 2 that it will not reach

a safe moisture content merely by exposure to the atmosphere, so that artificial drying is necessary. This is done by peasant farmers who hang the ears of grain above a slow fire. Recently, Government Agricultural Stations and the University College have installed artificial dryers capable of dealing with several tons of maize at a time. When dry, the grain still has to be stored through several months when the humidity is high, and grain in small quantities will then rapidly reach a moisture content which will seriously affect its viability. In

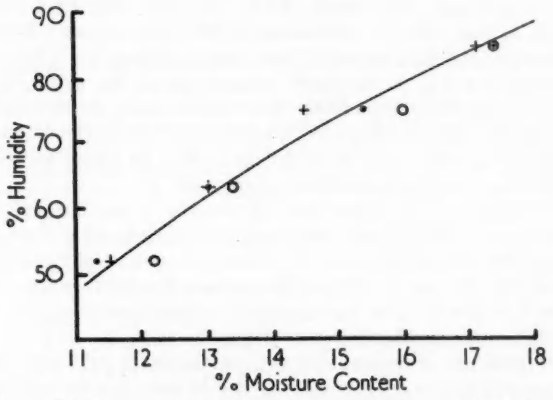

FIG. 2. Moisture content of maize in equilibrium with different percentages of Relative Humidity.

Key to Fig. 2. ● Ikom White, W.A.M.R.U. Progeny No. 5984
+ Mexican I, ,, ,, No. 6391
o Haiti, ,, ,, No. 5516

larger quantities only the outer few inches of grain are affected, and it has been found that at a depth of 9 inches, grain stored at a moisture content of 12 per cent. in July will not have increased to more than 13·5 per cent. by the end of October. Small quantities of grain should therefore be protected by sealing in air-tight containers, larger quantities will be safe providing the upper few inches of grain are discarded before planting.

The importance of moisture content is increased when grain has to be fumigated. If the storage is not air-tight the fumigant evaporates rapidly, so minimizing its effect on subsequent seedling growth; the grain is exposed to reinfestation and also to high humidity with a consequent increase in moisture content. If the storage is air-tight the danger of damage by fumigant is increased but the grain is protected from reinfestation and its moisture content will not increase as a result of exposure to the atmosphere. In this case it is essential that the moisture content should be as low as possible and the grain should be kept as cool as possible, so as to minimize the effect of the fumigant.

It is evident that viability and seedling vigour will be seriously impaired if grain is dried at harvest time and is subsequently kept in open stores and fumigated when insect infestation becomes heavy some months later, when its moisture content has risen as a result of exposure to high atmospheric humidity.

The observation of Cotton and Gray [3], that a mixture of ethylene dichloride and carbon tetrachloride is a safe fumigant at all moisture contents, calls for special comment. Their 3:1 mixture contained more ethylene dichloride than that employed in the trials reported here where a 1:1 mixture was used. It is unlikely that this difference in composition of the mixture accounts for the discrepancy between their observations and those reported here, since ethylene dichloride has already been shown [1] to be more damaging to the grain than carbon tetrachloride. Instead, it is likely that under temperate conditions the fumigant may be safe at all moisture contents, for it has been shown [1] that damage resulting from fumigation is less in grain stored at about 75° F. than it is for grain stored at about 80° F.

Results similar to those discussed above for maize have also been obtained from a study of cowpea seedlings raised from seed fumigated with the 1:1 mixture of ethylene dichloride and carbon tetrachloride [2].

These additional data stress the importance of considering both growth and yield as well as germination when assessing the effect of a fumigant on seed intended for planting.

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MANURING OF COTTON IN WEST PAKISTAN.[1] IV. EFFECT OF THE SOURCE OF NITROGEN ON THE YIELD OF SEED COTTON

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Summary

Various organic and inorganic sources of nitrogen were used at the rate of 50 lb. nitrogen per acre. The organic sources gave relatively lower increases in yield. Amongst the inorganics, urea and ammonium sulphate gave similar increases in yield; but urea was found to be the cheaper source of nitrogen for cotton.

A critical experimental study of the effects of different times and methods of fertilizer application to cotton is considered desirable, with a view to improving the relatively low efficiency of fertilizer use on cotton by current methods.

SEVERAL sources of nitrogen, organic and inorganic, may be utilized as fertilizers for cotton. Amongst the organics, farmyard manure and cottonseed cake were available in comparatively large quantities. Ammonium sulphate, ammonium nitrate, and urea were selected as inorganic sources of nitrogen. The purpose of this investigation was to study the relative efficiency of these various organic and inorganic sources of nitrogen with respect to their effect on the yield of seed cotton.

Review of Literature

Work on the use of nitrogenous and other fertilizers in the Indo-Pakistan Sub-continent has been reported by Dastur [1], Panse [2], Stewart [3], and Vaidyanathan [4]. Several organic and inorganic sources of nitrogen have been compared. Amongst the inorganics ammonium sulphate, ammonium nitrate, sodium nitrate, calcium cyanamide, and urea were tried; but the number of experiments was too small to permit any firm conclusions. However, generally, ammonium sulphate appeared to be superior to other inorganic sources of nitrogen, while farmyard manure proved better than the other organic sources.

Materials and Methods

Experiments were laid out in 1953, 1954, 1955, and 1956 in randomized blocks at the Lyallpur Agricultural Farm, with six replications, using L.S.S. cotton variety. The net plot size was $\frac{1}{40}$ acre. Besides the control, there were six treatments in which ammonium sulphate, ammonium nitrate, urea, farmyard manure, cottonseed cake, and bonemeal were used, all at the rate of 50 lb. N per acre. Farmyard manure, cottonseed cake, and bonemeal were applied about a month before sowing, so that mineralization of the organic nitrogen would be well advanced at sowing

[1] Publication of the Department of Agriculture, West Pakistan. The scheme was partially financed by the Pakistan Central Cotton Committee, Karachi.

time, to avoid harmful competition of soil micro-organisms with the cotton seedlings. All the inorganic fertilizers were applied in a single broadcast between the rows at the pre-flowering stage, this being the time and method of application officially recommended by the Department of Agriculture, West Pakistan. The application of fertilizers was followed by an irrigation. Other operations were normal, i.e. cotton followed wheat, row-to-row distance was 2·5 feet, and five to seven 3-inch irrigations were applied, depending on the rainfall. In addition one 4-inch irrigation was applied for seed-bed preparation.

Results and Discussion

The yearly average yields of seed cotton in maunds[1] per acre are given in Table 1.

TABLE 1. *Average Yearly Yields of Seed cotton in maunds per acre*

Serial no.	*Treatment (50 lb. N/acre)*	*Years*			
		1953–4	*1954–5*	*1955–6*	*1956–7*
1	Control (no. N)	16·44	22·83	16·81	11·16
2	Ammonium sulphate . . .	21·83	24·55	16·90	12·63
3	Urea	17·48	26·56	18·53	12·88
4	Ammonium nitrate . . .	19·16	25·86	18·15	11·57
5	F.Y.M.	19·69	23·95	18·61	12·26
6	Cottonseed cake . . .	17·40	23·61	16·73	13·10
7	Bonemeal	19·64	24·00	16·80	10·10

The frequency at which a particular yield occupied the first, second, and the third positions indicates that the levels of responses in descending order of magnitude were from urea, ammonium sulphate, farmyard manure, ammonium nitrate, cottonseed cake, and bonemeal.

The data were statistically examined by the analysis of variance. Treatment effects were significant in the years 1954–5, 1955–6, and 1956–7, the critical differences at the $P = 0{\cdot}05$ level being 2·24, 1·60, and 2·33, respectively. The pooled analysis for four years showed that effects for both treatments and years were significant, the critical differences at the $P = 0{\cdot}05$ level being 1·47 and 1·11, respectively; treatment variance was significant despite high seasonal variations. This indicates that fertilizer use on the cotton crop may be effective under a range of climatic conditions.

To get a general picture, overall average yields, yield increases over control and per lb. of N, and the relative efficiency of various sources of nitrogen are given in Table 2.

The conclusions drawn from the data in Table 1 were based on the frequency of the higher relative levels of response of a particular treatment. Table 2 shows that the yield increases obtained with cottonseed cake and bonemeal were the lowest. The use of these two manures as fertilizers for cotton was thus relatively inefficient. Ammonium nitrate and farmyard manure gave similar yield increases. Assuming that the

[1] 1 maund = 82 lb.

price of ammonium (33 per cent. N) per maund is Rs. 12[1] and the cost of farmyard manure per ton containing 10 lb. N is Rs. 5, there was a gain of Rs. 5 per acre for ammonium nitrate in comparison with farmyard manure. Farmyard manure was better than cottonseed cake and bonemeal presumably because it was in an advanced state of decomposition and part of its nitrogen was therefore more readily available than that contained in the other undecomposed materials. Moreover, it seems that the cotton crop did not benefit from the phosphorus in bonemeal, probably because the available phosphorus in the soil was enough to meet the requirements of the crop.

TABLE 2. *Average for four years compared to Average Control Yield*

Serial no.	*Treatments (50 lb. N/acre)*	*Yields mds./acre*	*Yield increases mds./acre*	*Increase lb./lb. of N*	*Relative efficiency*
1	Control	16·81	..	..	..
2	Ammonium sulphate	18·98	2·17	3·6	100
3	Urea	18·86	2·05	3·4	94
4	Ammonium nitrate	18·68	1·87	3·1	86
5	F.Y.M.	18·63	1·82	3·0	83
6	Cottonseed cake	17·71	0·90	1·5	42
7	Bonemeal	17·64	0·83	1·4	39

TABLE 3. *Cost of Various Fertilizers in U.S. dollars and rupees*

Fertilizer	*Percentage N*	*Cost per short ton (2,000 lb.)*		*Cost per maund. Rupees*	*Cost per lb. of N. Rupees*	*Comparative cost per unit N*
		$	*Rupees*			
Ammonium sulphate	20·5	65·0	309·0	12·67	0·75	100
Ammonium nitrate	33·5	85·0	404·0	16·57	0·60	80
Urea	45·0	125·0	594·0	24·36	0·66	88

As between the responses to ammonium sulphate or urea the difference was small, but in favour of the former. The costs of the fertilizers given in Table 3 are those reported by Tisdale and Nelson [5].

The costs given in Table 3 are those prevalent in the United States in 1956. They show that nitrogen in the form of urea was cheaper than in either of the other two forms. Though the relative agronomic efficiencies of ammonium sulphate and urea were 100 and 94, the relative costs per unit were 100 and 88 respectively.

Table 4 clearly indicates that urea was the most economical source of N, on the basis of fertilizer prices in the United States. If freight costs and other shipping and handling charges are also taken into consideration, which will be barely half as much per unit of N for urea as for ammonium sulphate, the margin of profit with urea would be still greater. Thus it may be concluded that urea is the best inorganic source of nitrogen for cotton under the conditions obtaining for these experiments.

[1] One rupee is equivalent to $0·21 or 1*s.* 6*d.*

The time and method of application of the inorganic fertilizers were those recommended by the Department of Agriculture, West Pakistan. These are two very important factors which may largely determine the proper utilization of the fertilizers and their effect on yield. The responses obtained in Pakistan were much lower than those obtainable for the same quantity of nitrogen in other countries. It is therefore important to consider whether this may be due to the way the fertilizers were used.

TABLE 4. *Costs of Fertilizers and of Increased Produce*

Fertilizer	*Yield increases mds./acre*	*Return, at Rs. 30/md. of seed cotton. Rupees*	*Cost of fertilizer. Rupees for 50 lb. N*	*Profit. Rupees/acre*
Ammonium sulphate .	2·17	65·10	37·68	27·42
Ammonium nitrate .	1·87	56·10	30·13	25·97
Urea . . .	2·05	61·50	33·00	28·50

Nitrogen Metabolism of the Cotton Plant, considered in Relation to the Time and Method of Application of Nitrogen Fertilizers

In the past, the time of application of fertilizers to cotton seems to have been based more on certain other facts rather than on direct experimental evidence. It had been observed that there was commonly a heavy shedding of early flowers in the Punjab–American cottons, due to the non-dehiscence of anthers. Early applications of nitrogen were therefore believed to be wasteful. Moreover, Madhok and Din [6] claimed that there was practically no naturally available nitrogen in the soil at the effective flowering stage, and therefore that the addition of fertilizer nitrogen at this stage was necessary. On this basis, Afzal [7] conducted experiments to find the best time of application of inorganic fertilizers to cotton, and concluded that the best time of application was about the end of August, but the amount of experimental evidence was meagre.

Crowther [8] also supported the late application of nitrogen under Punjab conditions on the grounds that since the clay content of the Punjab soils was low, so that with irrigation the nitrogen fertilizers were not retained near the surface and if applied earlier they would leach down below the root zone.

Since these views were accepted, in all these experiments inorganic fertilizers were applied in August.

Several workers [9, 10, 11, 12, 13, 14, 15, 16] had noted that commonly there were ample quantities of nitric nitrogen in the soil solution during the active growth period of plants, while at the later stages of growth nitric nitrogen was generally practically undetectable. This could be explained by supposing that the plants stimulated nitrification during their active growth but exerted a depressing effect at the later stages of growth, and such an influence was ascribed to the supply of carbonaceous matter from plant roots, which favoured the development

of nitrate-consuming soil micro-organisms and consequently resulted in nitrogen starvation of the plant.

Theron [17], however, explained these observations on the hypothesis that the plant interferes with the oxidation of ammonia to nitrate. He further stated that the sensitiveness of the nitrifying organisms to soluble organic matter, as demonstrated *in vitro*, makes their autotrophic existence in the soil vulnerable to bateriostatic excretions of living roots. On this basis, the absence of nitrates from the soil at the later stages of growth would not necessarily imply lack of minerizable soil nitrogen, but it could mean that nitrate fertilizers would be more beneficial than those applying ammonium nitrogen. This view is supported by the findings of Naftel [18] who reported that seedling cotton utilized ammonia nitrogen more efficiently than nitrate nitrogen, but that at a later stage both growth and fruiting were favoured when both forms of nitrogen were present.

Crowther [19] found that 60 per cent. of the total nitrogen of the cotton plant was in the squares and bolls from the time the first boll started to open until the maturity of plant. As the fruit-setting proceeds, nitrogen migrates from the leaves to the bolls faster than it reaches the leaves from the soil through the roots. This results in exhaustion of nitrogen reserves in the leaves and causes their yellowing. This onset of nitrogen starvation could be delayed by the addition of nitrogen fertilizers which will increase leaf nitrogen and leaf area and thus bring about greater synthesis of carbohydrates. More nitrogen and carbohydrates will then be translocated to the bolls and will increase their number and size. When ammonia nitrogen is applied as a fertilizer, particularly at a later stage of plant growth, its nitrification may be depressed and its beneficial effect reduced. The successive stages of nitrification, uptake by the plant, reduction and conversion into amino-acids, transportation to the leaves, conversion into proteins, and final translocation to the fruits, involves a lag period which may result in nitrogen starvation of the plant. On the other hand, early application of ammonia nitrogen will favour efficient utilization of nitrogen, which may cause greater vegetative growth and produce reserves of proteins for ready transference to fruits, and may even stop the shedding of flowers.

In spite of much work in other countries, no satisfactory explanation for flower shedding is available. Hence the comparatively low response of cotton to nitrogen fertilizers in Pakistan may be due to improper time of application of the fertilizers. It is the authors' belief that better results would be obtained if half of the 50 lb. of nitrogen used per acre were applied at the seedling stage and half at the end of August.

Crowther's explanation to support late application of inorganics is considered untenable, because nitrates will leach under any circumstances after irrigation, while ammonia nitrogen will be fixed by the soil clay and remain in the root zone. The quantities of ammonia nitrogen used in practice are such that the clay content of Punjab soils is quite enough to prevent its leaching.

With regard to method of application, Wahhab *et al.* [20] have shown that a 40-to-50-per-cent. loss of ammonia took place through volatiliza-

tion, when ammonia sulphate was broadcast on the soil surface in a single application (as in the experiments here reported and as generally practised at the present time). However, the loss was markedly reduced by placement of ammonium sulphate below the soil surface. The losses were further minimized by lowering the concentration of the fertilizer. There are thus good grounds for believing that the effectiveness and profitability of fertilizer use on cotton in West Pakistan might be increased by using different times and methods of application. The conduct of experiments on this subject is therefore highly desirable.

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FERTILIZER EXPERIMENTS WITH PHOSPHORUS, NITROGEN, AND SULPHUR IN GHANA

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Summary

Experiments comparing types of phosphatic and nitrogen fertilizers, and methods of applying single superphosphate, are described. The residual effects of single superphosphate on the yields of succeeding crops are estimated, and the evidence for sulphur deficiency in Ghana is summarized. Single superphosphate and ammonium sulphate are the fertilizers recommended for general use in Ghana, especially in the savannah zone; the residual effects of the former were large.

FERTILIZER experiments on food crops in Ghana were initiated by Nye [1]. By 1953 his work had shown that nitrogen and phosphate fertilizers could be profitably used and it became necessary to find out what forms of these fertilizers should be recommended and how they should be applied. This information was particularly required in the far north where farmers were already being encouraged to use fertilizers on their groundnuts and where, in view of the heavy cost of transport from the ports 500 miles away, more concentrated fertilizers and more efficient methods of application might be expected to be crucially more profitable. This paper describes and discusses the experiments which were laid down with these aims. It considers in turn those comparing different forms of phosphate, the methods of application, residual effects, different forms of nitrogen fertilizers, and the evidence for sulphur deficiency in Ghana.

Experimental Sites

The stations and localities where experiments were conducted are shown in Fig. 1 together with the main vegetational and geological zones of the country. The soils of Ghana have yet to be adequately classified; but, with regard to fertilizer responses of soils of the upper slopes, which are usually favoured by farmers and on which nearly all the experiments were sited, these stations and localities may be grouped thus:

Pokoase in the costal-scrub and grassland zone, with soils derived from granite. Annual rainfall 38 in. with two peaks (in June and October); top soils (0–6 in.) of dark-brown (Munsell 10YR/4/3 when dry) coarse sand with much quartz and ironstone gravel and a sandy-clay subsoil overlying compact sandy clay.

Kwadaso in semi-deciduous forest over granite. Annual rainfall 58 in. with two peaks; grey-brown (10YR/5/2) gravelly-sandy loam top soil becoming heavier with depth and with a permeable layer of quartz and ironstone at about 3 ft.

Ejura, *Damongo*, and *Nyankpala*, in Guinea-savannah woodland over Voltaian sandstones. Annual rainfalls Ejura 58 in. with two peaks, and

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Damongo 47 in. and Nyankpala 43 in., each with a single peak; brown (10YR/4/3) to reddish-yellow (7·5YR/6/6) medium sands becoming more clayey with depth. Concretionary hard-pan layer usually occurs about 3 ft. down at Ejura and at about 2 ft. at Nyankpala.

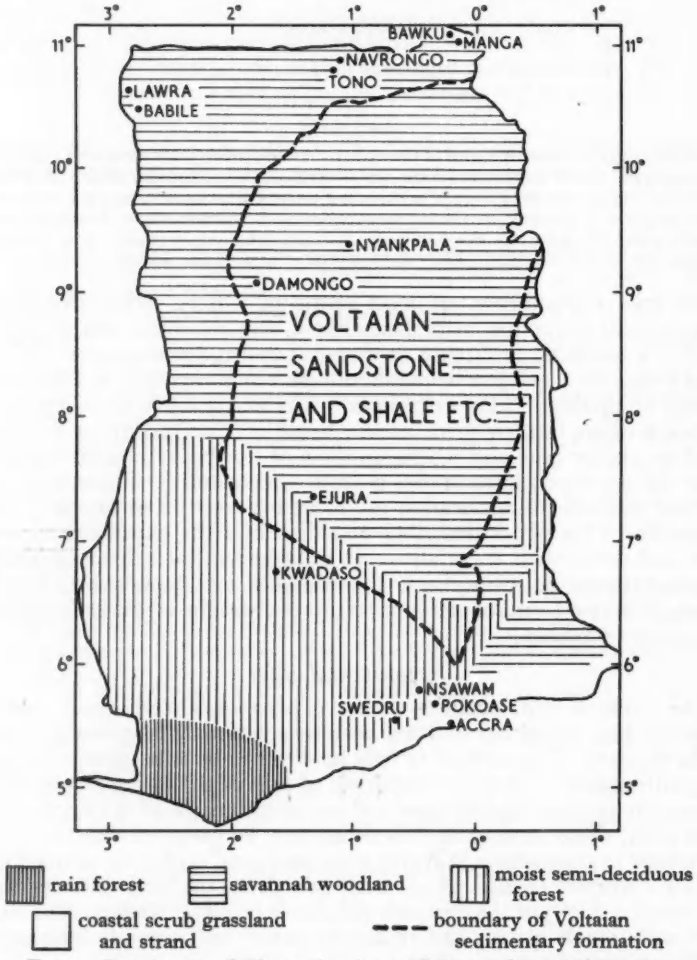

FIG. 1. Sketch map of Ghana showing trial sites and vegetation zones.

Babile, *Tono*, and *Manga*, in Guinea-savannah over granite. Annual rainfalls (single peak) Babile 48 in., Tono 43 in., Manga 39 in.; light yellowish-brown (10YR/6/4) gravelly coarse sand top soils grading into clayey coarse sand subsoils usually with ironstone gravel or hard-pan at about 3 ft. overlying compact mottled gritty sandy clay. These stations

are typical of much of the nearby farming areas around *Lawra*, *Navrongo*, and *Bawku*, although brown gravelly sandy clay soils derived from greenstone (metamorphosed lavas or tuffs of the Upper Birrimian) also commonly occur in the latter.

The maize areas around *Nsawam* and *Swedru* in the southern fringe of the semi-deciduous-forest zone bordering on the coastal scrub and savannah. Mainly over granite or Lower Birrimian phyllites.

At all sites the pH of the top soil (0–6 in.) was about 6; the savannah top soils had less than 1 per cent. organic carbon and 5 m.e. per 100 gm. exchange capacity, while the figures for forest sites were around 1·5 and 10 respectively.

Forms of Phosphatic Fertilizers

The first experiments in Ghana with different forms of phosphatic fertilizers, and methods of application, were 3^4 factorial experiments conducted on Department of Agriculture stations in 1950 and 1951 [2]. Since then there have been: one 3^3 factorial experiment at Damongo, in which the treatments were identical with the above-mentioned 3^4 experiments except that the factor of application time was omitted; and a number of simpler experiments in which forms of phosphate and methods of application were separately studied. Of these experiments, which paid special attention to northern Ghana, those comparing different forms of phosphate may be grouped thus:

Experiments on Agricultural Stations

(*a*) Five 6×6 Latin squares, each repeated on the same site for a second year, compared broadcast applications of granular single superphosphate (18 per cent. P_2O_5), 'triple' superphosphate (40 per cent. P_2O_5), ammonium phosphate (16 per cent. N and 20 per cent. P_2O_5), gypsum, and one of the alternatives: (i) a 50–50 mixture, by weight, of powdered rock phosphate and single superphosphate or, where rock phosphate was not available, either (ii) a 50–50 mixture of gypsum and single superphosphate, or (iii) a half-rate of single superphosphate alone. Direct effects of the fertilizers were measured on maize or guinea corn at Kwadaso and Ejura and on groundnuts at Babile, Tono, and Manga; residual effects were taken on second-season groundnuts at the first two sites and on third-year millets and guinea corn at the last three. Plot size was $\frac{1}{45}$th acre (except at Babile, $\frac{1}{65}$ acre). The ammonium phosphate used was assumed to contain 48 per cent. P_2O_5, but it was later discovered that it had only 20 per cent.; the ammonium phosphate treatments had thus supplied only 9 lb. P_2O_5 per acre against the single and 'triple' superphosphate rates of approximately 21 lb. P_2O_5.

(*b*) Two randomized block experiments on groundnuts at Babile and Manga. These included broadcast treatments of granular single superphosphate, 'triple' superphosphate, powdered rock phosphate (33 per cent. P_2O_5), and Hyperphosphate (very finely divided rock phosphate, 27 per cent. P_2O_5) each at 21 lb. P_2O_5 per acre. Plot size was $\frac{1}{37}$ acre.

Extension Experiments on Native Farms

In these experiments agricultural staff sprinkled the fertilizers around the plants a few weeks after planting and also harvested the crop, while the farmer planted, weeded, and cultivated in his normal way. There were three series, each with a plot size of $\frac{1}{40}$ acre: (*a*) sixty-three maize experiments of 2×3 NP factorial design around Nsawam and Swedru with the treatments: N = ammonium sulphate at 0 and 60 lb. per acre; P = 60 lb. single superphosphate and 25 lb. 'triple' superphosphate per acre. (*b*) eighty-eight groundnut experiments around Lawra, Navrongo, and Bawku in 1955, in which the above phosphate treatments were tested without adding nitrogen. (*c*) Fifty-three groundnut experiments in 1956 in the same areas as (*b*), in which the treatments were 120 lb. single superphosphate, 50 lb. 'triple' superphosphate, 80 lb. gypsum, and a mixture of 50 lb. 'triple' superphosphate + 80 lb. gypsum per acre.

Results

As single superphosphate was included in all the experiments and is the phosphatic fertilizer most commonly used in Ghana, the effects of the other treatments have been expressed by comparing them with that of single superphosphate. The following results include all the experiments, including the earlier 3^4 factorial experiments.

'Triple' versus single superphosphate. The mean yields are summarized in Table 1 (A and B). The levels of P_2O_5 varied slightly between experiments because plot sizes had to be modified to fit some of the sites and because the responses in the 3^3 and 3^4 factorial trials were taken to be the means of those at the higher and lower rates; but in any one trial the levels of P_2O_5 supplied by the two fertilizers did not differ by more than 10 per cent. Individual rates ranged from 11 to 22 lb. P_2O_5 per acre.

In the forest and fringing-forest experiments (both station and extension) the direct effect of 'triple' superphosphate was approximately equal to that of single, while its residual effect on maize at Kwadaso was significantly greater. Under present conditions in the southern part of Ghana it seems, therefore, that 'triple' superphosphate will be as effective as single and, because its transport costs per lb. P_2O_5 are lower, it should be the more economical form to use. However, as transport cost does not add very greatly to the price of fertilizers in areas near the ports, this advantage of 'triple' superphosphate may not be very important in southern Ghana. In the savannah woodland on soils formed over Voltaian sandstones, single superphosphate significantly outyielded 'triple'. As will be discussed later, this may be due, at least in part, to the sulphur content of the former, but, for whatever reason, the evidence of these few experiments is that single is to be preferred to 'triple' superphosphate in this zone.

In the savannah woodland of northern Ghana the results of the station and extension experiments differ. At the agricultural stations the effects of the fertilizers, both directly on groundnuts, and residually on cereals, were almost identical, and, in view of the long distance from the coast, it was expected that 'triple' superphosphate would be definitely the more

TABLE 1. *Comparative Yields with Single Superphosphate, 'Triple' Superphosphate, and Ammonium Phosphate.*

TABLE 1. *Comparative Yields with Single Superphosphate, 'Triple' Superphosphate, and Ammonium Phosphate, at equivalent rates of* P_2O_5 *(11 to 22 lb. per acre)*

A. *Trials on Agricultural Stations*

Direct or Residual effect	*Zone*	*Crop*	*No. of season trials*	*No. of separate sites*	*Mean yields in lb./acre*				*L.S.D.* ($P = 0{\cdot}05$)
					No phosphate	*Single super*	*Triple super*	*Ammonium phosphate*	
Direct effects	Forest granite	Maize	5	3	282	328	351	361	45
	Savannah-sandstone	Cereals	4	2	1,018	1,302	1,133	1,313	139
		Groundnuts	3	3	373	503	421	384	68
	Savannah-granite*	Groundnuts	11	8	565	743	751	..	39
		Groundnuts	9	6	522	663	688	611	41
Residual effects	Forest-granite	Maize	1	1	509	573	650	673	75
		Groundnuts	3	2	608	558	592	557	74
	Savannah-sandstone	Groundnuts	3	1	853	908	883	888	61
	Savannah-granite	Cereals	5	3	335	589	586	482	93

B. *Extension Trials on Peasant Farms (Direct Effects only)*

Zone	*Crop*	*Locality or year*	*No. of sites*	*Mean yields in lb./acre*			*L.S.D.* ($P = 0{\cdot}05$)
				No phosphate	*Single super*	*Triple super*	
Forest fringe bordering coastal scrub	Maize	Nsawam	36	1,449	1,326	1,239	141
		Swedru	27	799	959	1,039	178
North savannah mainly on granite soils	Groundnuts	1955	88	503	968	773	56
		1956	53	..	866	748	55

N.B. Ammonium phosphate yields have been computed as described in the text (p. 156).

* Ammonium phosphate was omitted from the two randomized block trials.

profitable form of phosphate to use. The extension trials showed, however (see Table I, B), that single superphosphate was highly significantly more effective than 'triple' on the local groundnut farms. A likely explanation of this difference is that the station soils, which used to receive dressings of farmyard manure every third year, before the trials started, were sufficiently well supplied with sulphur, whereas the native groundnut farms, being unmanured, had too little of this nutrient; it is also worth noting that even on the station soils of Tono and Babile (though not at Manga) yields of groundnut haulms were significantly greater with single than with 'triple' superphosphate. The question of sulphur deficiency is considered later and it suffices here to record that on the strength of these experiments single superphosphate is preferred for use in northern Ghana.

Ammonium phosphate v. *single and 'triple' superphosphate.* The comparison is complicated by the disproportionately low P_2O_5 content of the ammonium phosphate used in the Latin square experiments; to correct for this, ammonium phosphate responses in these experiments have been multiplied by the factor

$$\frac{\text{lb. } P_2O_5 \text{ actually applied by the superphosphate treatments}}{\text{,, ,, ,, ammonium phosphate treatments}}$$

to give an estimate of the responses which would have been obtained if the rate of P_2O_5 application had been equal to that of the superphosphates. As the response to a half-hundredweight dressing of fertilizer in Ghana is nearly always more than half that to one hundredweight, the comparative yields estimated in this way and quoted in Table I, A almost certainly overestimate the effectiveness of the ammonium phosphate. In spite of this, the table shows that on groundnuts at the savannah sites ammonium phosphate was outyielded by both superphosphates, and its residual effects on cereals on the granite soils of the northern savannah was also significantly the smallest. Owing to its nitrogen content, its direct effects on cereals would be expected to be especially large. Unfortunately the maize experiments on forest sites had exceptionally low yields owing to the rust epidemic of 1950–1 and do not give a fair measure of the relative effects of the fertilizers. At the two savannah sites on Voltaian-sandstone soils ammonium phosphate outyielded 'triple' and equalled single superphosphate, suggesting that there both nitrogen and sulphur were deficient.

Ammonium phosphate has not been tested in extension experiments in Ghana, but its use on native food farms would seem likely to be confined to non-leguminous crops such as maize in the south, where nitrogen and phosphorus may both be needed.

Rock phosphate v. *single superphosphate.* Rock phosphate was tested in two ways: (i) as a mixture with an equal weight of single superphosphate; (ii) in direct comparison with single superphosphate at equal rates of P_2O_5. Table 2 gives the yield results of both types of experiments, all carried out on agricultural stations in the savannah. The mixture did not give higher yields than single superphosphate alone, even though 1 cwt. of the former contained 30 lb. P_2O_5 as against 21 lb. in the latter;

TABLE 2. *Comparative Yields of (i) Single Superphosphate against 50/50 mixture of Single Superphosphate+Rock Phosphate at Equal Weights of 1 cwt. per acre, and (ii) Single Superphosphate against Rock Phosphate at Equivalent Levels of P_2O_5 (21 lb. per acre)*

Direct or residual effects	*Zone*	*Crop*	*No. of season trials*	*No. of separate sites*	*Mean yields in lb./acre*				*L.S.D.* ($P = 0{\cdot}05$)	*Treatment rates*
					No phosphate	*Single super*	*Rock phosphate*	*Rock+super mix*		
Direct effects	Savannah sandstone	Cereals	2	2	1,370	1,835	..	1,705	265	1 cwt. fertilizer/acre
	Savannah granite	Groundnuts	5	3	583	753	..	747	65	,, ,,
	,, ,,	,,	3	3	742	1,038	935	..	87	21 lb. P_2O_5 per acre
Residual effects	Savannah sandstone	Groundnuts	4	1	528	557	..	568	62	1 cwt. fertilizer/acre
	Savannah granite	Cereals	3	3	558	981	..	836	155	,, ,,
	,, ,,	,,	1	1	541	978	920	..	117	21 lb. P_2O_5 per acre

TABLE 3. *Yields from Different Methods of applying Single Superphosphate*

Direct or residual effects	*Crop*	*Sites*	*No. of trials*	*Mean yields of grain or kernels in lb. per acre*						*L.S.D.* ($P = 0{\cdot}05$)
				Without fertilizer	*Broadcast on flat before ridging*	*Broadcast on ridges then ridges split*	*Broadcast after final ridging*	*Placed 6" deep beside plant*	*Placed around plant*	
Direct effects	Maize	Kwadaso	2	420	488*	458*	..	525	443	98
	Groundnuts	Babile and Tono	4	588	698	749	..	743	807	95
	Groundnuts	Manga	2	913	..	1,046	1,056	1,026	1,008	189
	Groundnuts	All 3 sites	6	696	..	848	..	837	873	89
Residual effects	Groundnuts	Kwadaso	2	585	550*	685*	..	665	640	107
	Millets	Babile and Tono	2	489	676	704	..	760	759	133
	Millets	Manga	1	704	..	1,104	1,146	1,049	1,062	179
	Millets	All 3 sites	3	561	..	838	..	857	860	112

* These methods of application were modified at Kwadaso—see text (p. 158)

and in the two experiments with rock phosphate and single superphosphate each at 21 lb. P_2O_5 per acre, the former was significantly the less effective. As the present prices of the two fertilizers are about the same it seems unlikely that rock phosphate will be a profitable alternative to single superphosphate.

A specially prepared form of rock phosphate called Hyperphosphate was also included in the two randomized block experiments and was found to be as effective as the ordinary rock phosphate and significantly less so than single superphosphate.

Comparison of Methods of Applying Single Superphosphate

As mentioned above the first experiments were of 3^4 factorial design and have already been reported [2]. The later experiments in 1953 and 1954, all on agricultural stations, consisted of four experiments, each continued on the same site for a second year. These were 5×5 Latin squares or randomized blocks comparing four methods of application with a no-treatment control. Direct effects were measured on maize (Kwadaso) and on groundnuts (Babile, Tono, and Manga), while residual effects were taken on second-season groundnuts (Kwadaso) or third-year millets (at the other stations). Plot size was $\frac{1}{45}$ acre and rate of application was 68 lb. single superphosphate per acre (except in the second year at Manga when the double rate of 136 lb. was used). At Babile, Tono, and Manga in the north, where bullock ploughs are used to make ridges on the contour, the following four application methods were thought likely to be efficient and practicable: (i) broadcast on the flat before ridging (Babile and Tono); at Manga, where last season's ridges were merely split instead of first ploughing and then re-ridging, this treatment was changed to broadcasting after the final ridging; (ii) at a convenient time after germination, when the farmers would not be very busy, the superphosphate was placed in a hole about 6 in. deep near each plant (it was thought that this deep placement might be advantageous in case of drought); (iii) at a convenient time after germination the superphosphate was placed in a circle around each plant; (iv) furrows were ploughed, then the superphosphate was broadcast and the ridges split so that the final ridges lay along the original furrows, burying the fertilizer quite deeply. At Kwadaso, where native practice is to grow maize on the flat, the above treatments (i) and (iv) were altered to (i *a*) broadcast on the flat just before planting, and (iv *a*) at a convenient time after germination the superphosphate was placed around each plant and stirred into the soil.

Results

Nye has already discussed the results of the 3^4 factorial experiments [2] and concluded that there were only small differences between (i) broadcasting, (ii) running the powdered superphosphate in a band along the rows, and (iii) placing by spoon 2 in. from each plant. On the whole he favoured broadcasting.

In the 5×5 Latin square experiments, the yields of which are summarized in Table 3, the only significant difference between superphos-

phate treatments was at Babile and Tono, where placing around the plant was better than broadcasting before ridging. In 1953 the placement treatments were applied 14 to 25 days after planting, whereas in 1954 they were delayed to 26 to 43 days after planting and at Tono and Manga they were applied after the customary re-ridging cultivation. At every station the response to placing around the plant was slightly greater in 1953 than in 1954; furthermore, at Kwadaso and in 1954 at Manga, where the placement was not followed by re-ridging, the responses were disappointing. These statistically non-significant trends suggest that, to get the best results from the method of placing superphosphate around the plant, the application should be within 3 weeks of planting and should be followed fairly soon by re-ridging to stop the fertilizer being washed away. However, even when these points were disregarded, this method has given the best responses at the three northern stations, though not significantly so.

None of the tested methods of application has been found substantially more effective than the others and it seems more important to get many farmers to use superphosphate on groundnuts than to persuade a few farmers to apply the fertilizer in any specified manner. The main criterion for the recommended method should in fact be that it is easy for the farmer to do properly, and this entails (i) that the application should be carried out during a slack period before or after planting; (ii) that it should be difficult for the farmers to use grossly wrong amounts of fertilizer or apply it very unevenly; and (iii) that it should not be too troublesome or require too much labour. At present it is thought that in northern Ghana superphosphate is best applied by placing a pinch of the granular fertilizer around each groundnut plant; this is also the method which has yielded highest in the Latin square experiments.

The Residual Effects of Single Superphosphate in the Guinea-savannah

In 1954 Nye [2] reported the results of 3^3 factorial experiments with ammonium sulphate and single superphosphate in Ghana, in which the fertilizers were applied at the beginning of the first year of each experiment and residual effects were measured during the succeeding one or two years. Some later experiments which included superphosphate treatments in their first years have been continued in a similar manner for a second year without further fertilizer applications. The results of all these experiments have been combined, by assuming that the response to 60 lb./acre of fertilizer is two-thirds of the response that would have resulted from an application 120 lb./acre. Table 4 gives the simple unweighted means of the percentage responses (actual or calculated) to 120 lb./acre of single superphosphate on cereals and groundnuts on the Voltaian sandstone and granite soils of the Guinea-savannah. It will be seen that the first-year residual effect expressed as a percentage was, for all crops, well over one-half the direct effect; for cereals on the granite soils of the far north it was actually a higher percentage of the mean than was the direct effect. This surprising result may be due to the reduced yields of untreated plots after an extra year's cropping without manures, as suggested by Nye. It may also partly result from the sites and years of

the residual effect experiments being more favourable for fertilizer responses than those of the direct-effect experiments carrying the same crops.

One trial, at Manga, has been carried out to measure the direct and residual effects of single superphosphate in a more balanced manner than

TABLE 4. *Single Superphosphate's Residual Effects*

Zone of the Guinea savannah	*Crop*	*Per cent. response to 1 cwt. single superphosphate per acre*					
		Direct effect		*1st year residual*		*2nd year residual*	
		No. of trials	*Response %*	*No. of trials*	*Response %*	*No. of trials*	*Response %*
Voltaian sandstone soils	Cereals	6	11	11	9	4	6
	Groundnuts	6	11	5	8	2	19
	All crops	12	11	16	9	6	10
Granite soils	Cereals	6	30	14	36	..	..
	Groundnuts	11	25	3	15	1	18
	All crops	17	27	17	32	1	18
General mean for all crops		29	20	33	21	7	11

the experiments summarized above. It consisted of three blocks, each one bearing the crops of a different course in the station three-course rotation, so that in any one year all the crops of the rotation were represented. Each block had eight plots which had the following treatments (P = application of 1 cwt. single superphosphate per acre):

Year \ *Plot no.*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*
1954 . . .	P	P	P	P	..	..	..	..
1955 . . .	P	P	..	..	P	P	..	..
1956 . . .	P	..	P	..	P	..	P	..

Thus in each year all possible combinations of direct and residual effects are compared in the same block.

Table 5 summarizes the direct and residual effects for each crop, the 'Mean for all crops' in the table being a true weighted mean. The mean direct effect was significantly greater than both residuals, while the second-year residual was nearly significantly greater than the first.

It is concluded that in the Guinea-savannah zone of Ghana the residual effects of single superphosphate are considerable. After one year the effects on crop yields were usually well over half the direct effects, and in the second year the effect proportionately more than in the first. The sum of the residual effects of single superphosphate over two years was thus at least as large as the direct effect in the year of application.

Comparison of Types of Nitrogen Fertilizers

Five experiments with different types of nitrogen fertilizers have been conducted in Ghana, all on Department of Agriculture stations. Two

(Ejura and Damongo) were of 3^4 factorial design similar to those mentioned above, comparing ammonium sulphate (21 per cent. N), urea (46 per cent. N), and ammonium nitrate (35 per cent. N) at 12·5 and 25 lb. N per acre. Three experiments each consisting of eight randomized blocks with $\frac{1}{66}$ acre plots (one at Damongo and two at Nyankpala), compared broadcast applications of ammonium sulphate, urea, and (in two experiments) cyanamide (21 per cent. N), each at 35 lb. N

TABLE 5. *Residual Effects of 1 cwt. per acre Single Superphosphate in Manga Trial*

Crop	*Direct effect as per cent. of mean yield*	*Ratio of 1st year residual to the direct effect*	*Ratio of 2nd year residual to 1st year residual*
Early millet and guinea-corn . .	29	0·48	2·05
Early millet and late millet . . .	21	0·56	1·31
Groundnuts	16	0·79	1·00
Weighted mean for all crops . .	23	0·61	1·12

TABLE 6. *Yields with Ammonium Sulphate, Urea, Ammonium Nitrate, and Cyanamide at equal rates of Nitrogen*

Zone	*Crop*	*No. of season trials*	*No. of separate sites*	*Mean yields in lb./acre*					*L.S.D.* ($P = 0{\cdot}05$)
				No nitrogen	*Ammonium sulphate*	*Urea*	*Ammonium nitrate*	*Cyanamide*	
Savannah-sandstone	Cereals	5	5	528	838	577	..	..	141
		2	2	281	325	..	300	..	66
		2	2	760	1,540	..	..	1,020	289

per acre. All five experiments were cropped with maize and/or guinea-corn; their sites had probably not previously been cultivated for longer than two years.

Table 6 shows the mean cereal yield with each treatment. Although the experiments were few, and one suffered badly from maize rust, ammonium sulphate was the most effective, giving significantly higher yields than urea or cyanamide. Ammonium sulphate also has the great practical advantage of keeping much better in a humid tropical climate than fertilizers such as ordinary urea, ammonium nitrate, or Nitrochalk; its disadvantages are relatively heavy transport costs, and a long-term tendency to acidify the already slightly acid Ghanaian soils. Urea or Nitrochalk in forms which keep better would be welcome. At present only ammonium sulphate is recommended by the Department of Agriculture for use by farmers in the Voltaian-savannah zone.

Sulphur Deficiency in Ghana

In thirteen experiments with groundnuts in the Voltaian savannah on sites which had been rested under natural vegetation for ten or more

years, Nye [1] found that plants grown without ammonium sulphate or single superphosphate were yellowish throughout the growing season and that mean yield responses to 2 cwt./acre of these fertilizers were: N, +9 per cent.; P, +12 per cent.; and the interaction of these factors (NP), −8 per cent. These results suggested that the groundnuts were responding to the sulphur in the two fertilizers. In other areas, or on sites rested for shorter periods, ammonium sulphate lowered the yields of groundnuts, although on the short-rest Voltaian-savannah sites vegetative growth was increased. This evidence for the existence of sulphur deficiencies in Ghana was supported by the work of Greenwood [3] in northern Nigeria where, under conditions similar to those in the far north of Ghana, groundnuts sometimes responded to sulphur.

TABLE 7. *Yields with and without Gypsum, on Station Sites*

Zone	*Crop*	*No. of season trials*	*No. of separate sites*	*Yields in lb./acre*		*L.S.D.* ($P=0{\cdot}05$)
				Without gypsum	*With gypsum*	
Forest-granite	Maize	2	1	340	297	93
Savannah-sandstone	Cereals	5	3	1,405	1,568	183
	Groundnuts	2	2	947	888	79
Savannah-granite	Groundnuts	5	3	584	600	67

The experiments described above show that in the Voltaian savannah single superphosphate and ammonium sulphate were usually more effective than other types of fertilizers not containing sulphur, not only with groundnuts but also with cereals. Two other groups of station experiments must also be mentioned. In the first, which includes some of the 6×6 Latin square experiments already described, gypsum was one of the treatments used. The yield results of this group, summarized in Table 7, show that, even in the Voltaian savannah, gypsum did not significantly increase yields. The second group consists of three experiments with cereals (two at Nyankpala and one at Damongo) in which ammonium sulphate and urea were compared both with and without the addition of phosphate and gypsum. Without phosphate and gypsum, ammonium sulphate increased grain yields per acre by 487 lb. and urea by only 47 lb., the difference being significant. In the presence of phosphate and gypsum the yield responses per acre were 333 lb. to ammonium sulphate and 193 lb. to urea, the difference being non-significant. The sites in the Voltaian savannah for both these groups of experiments had, with one exception, either been cropped for one or more years or had been rested for a comparatively short period; the one site which had a long rest lasting right up to the year of the experiment was at Damongo where the natural vegetation was quite thick woodland and was thoroughly cleared and destumped before ploughing by tractor. None of the sites therefore fall into the category of long-rest sites recently hand-cleared from typical savannah vegetation of grasses and widely spaced trees and shrubs.

More conclusive evidence for sulphur deficiency comes from the

extension experiments on peasant farms. Although, in the station experiments in the northern granitic areas, grain or kernel yields were as high with 'triple' as with single superphosphate, the groundnut haulm weights were usually significantly greater with single superphosphate. More importantly, in the experiments on native farmers' groundnuts, single superphosphate significantly outyielded 'triple'. A further fifty-three groundnut experiments on these northern farms were laid down in 1956 to compare the effects of 120 lb. single superphosphate, 50 lb. 'triple' superphosphate, 80 lb. gypsum, and a mixture of 50 lb. 'triple' superphosphate and 80 lb. gypsum per acre. These experiments have already been mentioned briefly during the comparison of forms of phosphatic fertilizers. The mean kernel yields per acre for each treatment were:

'Triple' superphosphate alone, 748 lb. 'Triple' superphosphate+gypsum, 821 lb.

Gypsum alone, 660 lb. Single superphosphate alone, 866 lb.

Least significant difference ($P = 0{\cdot}05$), 55 lb.

Once again single superphosphate significantly outyielded 'triple' superphosphate or gypsum alone, but there was no significant difference between triple superphosphate+gypsum and single superphosphate. This confirms the view that the extra effectiveness of the single superphosphate was due to its gypsum content and that these unmanured farm soils are short of available sulphur.

Between 1950 and 1954, 111 experiments have been carried out on upland rice farms in the Voltaian-savannah zone. These were 3^2 NP factorial trials using ammonium sulphate (N) and single superphosphate (P). The mean yield responses to 1 cwt./acre of these fertilizers were: N, +42 per cent.; P, +10 per cent.; and the interaction of these factors (NP), −10 per cent. These figures show that single superphosphate had a small positive effect on its own, but not when used in addition to ammonium sulphate; they are most simply explained by supposing that the rice responded to nitrogen and also to the sulphur in both fertilizers. An alternative explanation is that the effect of single superphosphate was to promote growth of nitrogen-fixing algae (the superphosphate plots could usually be picked out from a distance by the green colour of the soil surface caused by algal growth), and that in the presence of sulphate of ammonia the extra nitrogen obtained from the algae was unimportant.

It is concluded that in the Guinea-savannah zone, both on the Voltaian sedimentary and the northern granite soils, single superphosphate or ammonium sulphate will usually be more effective than alternative N or P fertilizers which do not contain sulphur.

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THREE ROTATION EXPERIMENTS WITH GRASS FALLOWS AND FERTILIZERS

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Summary

Three field experiments are described in which four rotations, including 0, 1, 2, and 3 years' rest under grass, are compared in their effects on succeeding crops, each rotation being tested in combination with nine fertilizer treatments. Soil samples were analysed to supplement the information obtained from crop yields. In the first 5-year cycles of these experiments it appears that (i) in the forest zone the main deficiencies which developed under continuous cropping were those of potassium and, to a lesser extent, phosphorus, both of which were rendered more available by elephant grass fallows; (ii) the better soils of the Voltaian savannah lack nitrogen and phosphorus; grass fallows aggravated the former deficiency but built up or maintained higher levels of availability of other nutrients including phosphorus; (iii) the poor soils of the Voltaian savannah became progressively more deficient in nitrogen and phosphorus under continuous cropping; and, although inorganic fertilizers could maintain yields, periods of rest under rather poor stands of grass have not given any benefit.

In Ghana, as in much of Africa, shifting cultivation is still common and, with increasing population and shortening resting periods for the land, is becoming incapable of maintaining an adequate level of soil fertility. Other systems of agriculture must therefore be tested, such as those using inorganic fertilizers, and sown or planted fallows, instead of natural re-growth. This paper describes three long-term experiments, which have recently completed their first 5-year cycle, in which it was planned to measure the benefit of 1 to 3 years' rest under grass on succeeding crops, to elucidate the nature of any such benefit and to indicate to what extent inorganic fertilizers can take the place of the resting period.

Experimental Design

All three experiments were of the same design, consisting of five blocks, each with four main plots subdivided into nine sub-plots (making a total of 180 sub-plots in each experiment). The main plots in a block were designated A, B, C, and D and carried different 5-year rotations as follows:

A = 3 years of grass followed by 2 years under test crops
B = 1 year of crops then 2 years grass and 2 years test crops
C = 2 years of crops then 1 year grass and 2 years test crops
D = 3 years of crops followed by 2 years test crops (i.e. continuous cropping)

Each block started at a different phase of the rotation, so that in each year all phases of each rotation were represented and two blocks were under test crops (one in its first and the other its second test year). In a

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complete cycle of 5 years each block comes under test crops and each roatation treatment is replicated five times.

The nine sub-plots of a main plot received the nine fertilizer treatments of a 3^2 NP factorial scheme. Until 1955 the treatment levels were:

N at 0, 60, and 120 lb. ammonium sulphate per acre in each year of cropping.

P at 0, 60, and 120 lb. single superphosphate per acre in each year of cropping.

From 1955 the rates applied to the test crops only were doubled in two of the experiments (at Kwadaso and Nyankpala) whilst the third experiment (at Ejura) continued with the original rates. These fertilizer treatments were not applied when the main plot was under grass. They were broadcast over the sub-plots before ridging and planting; where there were two cropping seasons a year, all the fertilizers were applied at the start of the first season, with second-season crops having only the residues of the first-season application. Other nutrients were not included because, when the experiments started, the evidence was that their effects were small in comparison with nitrogen, phosphorus, and sulphur [1]. However, later work has shown that severe potassium deficiencies develop in the forest zone after some years continuous cropping, so that it is perhaps unfortunate that this nutrient was omitted from the treatments.

Experimental Sites

The trials were laid down at Agricultural Stations, one starting in 1949 at Nyankpala, and the other two in 1950 at Kwadaso and Ejura. Notes on these sites follow:

Kwadaso. Six miles from Kumasi, the capital of Ashanti, in the moist semi-deciduous forest zone [2]. Annual rainfall 58 inches with two wet seasons, March–July and September–November. Experiment sited on upper slope on well-drained soil derived from Cape Coast granite [3], which after cultivation has dark yellowish-brown (10YR4/4 dry) gravelly-coarse-sandy loam top soils, grading into reddish-brown sandy clays with accumulation of quartz and ironstone gravel at about 18 inches depth, probably changing to mottled sandy-clay at about 5 feet and eventually merging into rotten granite. According to Charter's classification this soil is a forest ochrosol [4]. The site was under secondary forest before it was cleared for the experiment and the cut vegetation burnt on the site.

Ejura. Sixty miles north of Kumasi and in the Guinea-savannah woodland [2]. Rainfall 58 inches with two wet seasons. Experiment on upper slope of gently undulating land. Well-drained soil over sandstones of the upper Voltaian sedimentary formation [3] with top soil (after cultivation) of brown (7·5YR5/4 dry) medium sand with no gravel, a subsoil of sandy light loam or clayey sand and an ironstone concretionary pan at about 3 feet; probably classified as savannah ochrosol [4]. The site was under grass and scattered trees and bushes for more than 7 years before it was cleared for the experiment.

Nyankpala. Twelve miles west of Tamale, the capital of Northern

Ghana, in the Guinea-savannah woodland. Annual rainfall 43 inches with one rainy season May–October and a severe dry season. Experiment sited on the lower slope of gently rolling land over Obossum beds of the Lower Voltaian formation. Top soil of brown (7·5YR5/4 dry) medium sand becoming more clayey with depth and with an ironstone concretionary layer at about 2 feet; the soil has poor internal drainage and may perhaps be classified as an ochrosol-groundwater laterite intergrade. The site had probably been cropped fairly frequently before it was acquired by the government in 1947 and the grass bush may have been burnt every one or two years.

Results

Yield data from the experiments have been examined in two main ways. Test crop yields have been analysed to show the effects of the rotation treatments, the fertilizers, the number of years the experiment has run, and all first-order interactions of the above. Secondly, yields from all continuously cropped plots have been analysed for the effects of fertilizers, years of continuous cropping, and their interactions. The chief results of these calculations are summarized in Tables 1 to 5. Table 6 records some yields of cut grass on each experiment. Soil samples were taken from sub-plots of each experiment when it was started and from blocks in the experiment as they entered their test years. The results of the soil analyses are presented in Tables 7 to 9. Reference to these tables will be made when each experiment is separately considered below.

Kwadaso Experiment

Elephant grass (*Pennisetum purpureum*) was used as the fallow, planted 3 feet apart until 1955, but later at 18-inch spacing in order to get better coverage. It was cut once a year to destroy bird and rodent nests, the cut grass being left on the plots, and at the end of the resting period the grass was cut and burnt on the plots a few weeks before ridging and planting. In some years yields of grass were estimated before burning; these figures are given in Table 6.

The cropping sequence of each rotation was as follows:

Year 1	*Year 2*	*Year 3*	*Year 4* (*1st test year*)	*Year 5* (*2nd test year*)
A. Grass	Grass	Grass	Maize (1) Groundnut (2)	Maize (1) Grass (2)
B. Cassava	,,	,,	,, ,,	,, Cassava (2)
C. ,,	Maize (1) Groundnut (2)	,,	,, ,,	,, ,,
D. ,,	Maize (1) Groundnut (2)	Cassava	,, ,,	,, ,,

The experiment suffered much from crows (skilled at digging up newly planted groundnuts), weaver birds (which attack maize), and various rodents. As it was laid out on the contour around the summit of a small, moderately steep hill, the blocks were very spread out. This not only made intra-block comparisons less exact but also presented

TABLE 1. *Mean Yields of Test Crops in the Trial Rotations*

Site	Test year	Crop	Mean yields in lb./acre of grain or kernels: Rotation A (3 years' rest)	Rotation B (2 years' rest)	Rotation C (1 year's rest)	Rotation D (No rest)	L.S.D. ($P = 0.05$)
Kwadaso	1st	Maize	994	1,081	978	656	79
	1st	Groundnuts	366	483	438	361	41
	2nd	Maize	1,000	1,081	922	567	93
Ejura	1st	Maize	1,268	954	1,107	1,286	102
	1st	Groundnuts	802	774	701	672	46
	2nd	Maize	1,881	1,535	1,425	1,464	131
Nyankpala	1st	Maize	432	381	434	519	73
	2nd	Guinea corn	384	383	407	381	56

TABLE 2. *Mean Effects of Fertilizers on the Test Crops*

N_1 = Effect of single rate of ammonium sulphate
N_2 = Effect of double rate of ammonium sulphate
P_1 = Effect of single rate of single superphosphate
P_2 = Effect of double rate of single superphosphate

Site	Test year	Crop	Mean yield (lb./acre)	Effects of fertilizer treatments in lb./acre: N_1	N_2	P_1	P_2	5% sig. level	Significant N_2P_2 interactions
Kwadaso	1st	Maize	927	−32	22	220	201	68	Not. sig.
	1st	Groundnuts	413	22	12	2	26	35	,,
	2nd	Maize	892	51	−11	277	296	81	,,
Ejura	1st	Maize	1,154	166	322	32	66	88	,,
	1st	Groundnuts	738	13	−4	−5	−18	39	,,
	2nd	Maize	1,577	167	158	248	317	112	,,
Nyankpala	1st	Maize	442	233	322	299	376	64	280
	2nd	Guinea corn	389	103	213	192	203	49	72

TABLE 3. *Fertilizer Effects differing significantly between Rotations*

Trial	Crop details	Effect of double rate of ammonium sulphate (N_2) in lb./acre: A	B	C	D	L.S.D. ($P = 0.05$)
Ejura	Maize in 1st test years	370	403	440	77	253
Nyankpala	Maize in 1st test years	287	380	453	167	183

TABLE 4. *Mean Effects of Fertilizers on Groundnut Kernel Yields on the Continuously Cropped Plots*

Site	No. of years	Mean yield (lb./acre)	Effects in lb./acre: N_1	N_2	P_1	P_2	L.S.D. ($P = 0.05$)
Kwadaso	7	404	8	−11	52	95	31
Ejura	7	548	−4	−49	63	27	43
Nyankpala	9	427	−2	−18	56	59	49

TABLE 5. *Significant Trends of Yields and Responses on Continuously Cropped Plots*

Trial	*Crop*	*Response or yield under consideration*	*Units*	*Calendar years*									*Significant trends*
				1949	*1950*	*1951*	*1952*	*1953*	*1954*	*1955*	*1956*	*1957*	
Kwadaso	Maize	Response to superphosphate, 120 lb./acre	%	..	..	..	14	27	58	63	87	51	•
	Cassava	Mean yield	cwt./acre	..	..	120	95	86	73	49	65	58	•
Nyankpala	Maize	Yield without ammonium sulphate	lb./acre	642	617	475	475	542	208	358	475	158	•
		Response to amm. sulphate, 120 lb./acre	%	29	−14	5	0	20	60	65	26	195	•
		Yield without superphosphate	lb./acre	542	500	233	333	425	67	350	267	100	•
		Response to superphosphate, 120 lb./acre	%	48	37	164	95	77	525	50	197	417	•
		Yield with amm. sulph.+super.	lb./acre	844	644	587	544	775	437	662	894	687	
	Guinea corn	Yield without ammonium sulphate	lb./acre	808	500	317	308	333	258	183	300	375	•
		Yield without superphosphate	lb./acre	850	342	426	233	275	308	158	308	142	•
		Yield with amm. sulph.+super.	lb./acre	731	687	506	412	456	350	512	569	556	

• = significant at $P = 0{\cdot}05$

wide frontages to surrounding uncultivated strips from which the pests could raid the crops. Since 1955 test crops have been fenced to reduce this damage. Rust (*Puccinia polysora*) attacked maize with progressively decreasing severity after the initial epidemic in 1950.

From Table 1 it will be seen that crops of maize in the rotation with no resting period yielded highly significantly less than any of the rotations which included rests, and that groundnut yields in the no-rest rotation were highly significantly less than in rotations B or C. Significant differences between the rotations A, B, and C were: B better than A or C for first-year maize, B better than C for second-year maize, and B better than C which in turn outyielded A, with groundnuts. The conclusion is that resting under grass considerably increases the yields of succeeding crops and, although the precise number of years under grass is less important, 2-years' rest has produced the best yields so far—incidentally it also seemed on average to produce the biggest weight of cut grass (see Table 6).

TABLE 6. *Yields of Grass cut in January or February at the end of the Resting Periods*

Trial	*Year*	*Mean grass yields cut on rotation plots, in tons/acre*		
		A	*B*	*C*
Kwadaso . .	1955	9·6	10·6	13·7
	1956	10·8	22·7	15·6
	1957	10·3	9·7	12·0
Ejura . .	1957	6·6	6·2	6·4
Nyankpala .	1955	5·8	5·1	5·5
	1956	2·9	2·3	2·2

No interactions between rotations and fertilizers were significant, although there was a non-significant indication that ammonium sulphate increased yields of maize following at least 3 years under grass. It appears, therefore, that the main function of the rest period was probably not the supply of available phosphorus, and that there was no appreciable nitrate shortage after the grass fallow. The interactions between rotations and experimental years were significant for all the crops; but the only discernible trend was that the longer periods of rest may have become progressively more effective with first-year maize; this trend was not, however, statistically significant.

Ammonium sulphate had no significant effect, whether directly or in its interactions. This is in agreement with the results of other experiments on forest soils in Ghana in which responses to nitrogen and sulphur have usually been negligible. The figures in Table 2 show that superphosphate increased yields of maize test crops but had no significant residual effect on the groundnuts; on maize the lower rate of application was as effective as the higher, indicating that the crop was not severely short of phosphorus. Although groundnut test crops did not on the average respond significantly to superphosphate, if the responses on the

TABLE 7. *Mean Values for Analyses of Soil under the different Rotations at Each Site*

Analytical determination	*Soil horizon (in.)*	KWADASO						EJURA						NYANKPALA					
		A	*B*	*C*	*D*	*L.S.D.*	*Significant differences*	*A*	*B*	*C*	*D*	*L.S.D.*	*Significant differences*	*A*	*B*	*C*	*D*	*L.S.D.*	*Significant differences*
No. of block replications	0–6	7 except for Ex. Mg where 3 only						3 except for Ex. Ca where 1 only						4					
	6–12	6 except for Ex. Mg where 2 only						3 except for Ex. Ca where 1 only						None					
pH	0–6	6·31	6·49	6·47	6·16	0·17	B & C > D; B > A	6·40	6·50	6·45	6·34	0·20	None	5·90	5·88	5·76	5·80	0·13	A > C
	6–12	6·00	6·20	6·38	6·10	0·18	C > others; B > A	6·26	6·32	6·22	6·25	0·23	None						
Acid-soluble + adsorbed phosphorus (p.p.m. of P)	0–6	5·9	6·3	5·7	4·6	1·7	None	4·3	3·3	3·6	3·2	1·0	A > D	2·7	2·6	2·3	3·0	0·9	None
	6–12	2·0	2·2	2·4	1·8	0·5	C > D	2·1	1·9	2·2	2·1	0·5	None						
Organic carbon, % .	0–6	1·42	1·42	1·65	1·46	0·14	C > others	0·58	0·54	0·48	0·46	0·06	A & B > C & D	0·38	0·34	0·36	0·31	0·04	A & C > D
	6–12	0·75	0·75	0·81	0·79	0·09	None	0·41	0·38	0·37	0·35	0·06	A > D						
Nitrogen (p.p.thou.) .	0–6	1·28	1·25	1·41	1·33	0·09	C > A & B	0·40	0·40	0·37	0·34	0·04	A & B > D	0·34	0·32	0·33	0·32	0·04	None
	6–12	0·68	0·68	0·66	0·71	0·09	None	0·35	0·31	0·32	0·30	0·05	A > D						
Exchange capacity (m.e. per 100 g.) . . .	0–6	8·7	8·8	9·9	9·4	0·7	C > A & B	4·5	4·2	5·0	4·1	0·8	C > D	3·8	3·8	3·8	3·4	0·3	Others > D
	6–12	5·6	5·6	6·0	5·7	0·6	None	3·9	3·7	4·2	3·9	0·9	None						
Exchangeable K (m.e. per 100 g.) . . .	0–6	0·22	0·23	0·22	0·11	0·03	Others > D	0·28	0·30	0·24	0·25	0·03	A & B > C & D	0·23	0·26	0·22	0·23	0·03	None
	6–12	0·11	0·14	0·10	0·06	0·03	B > others; A & C > D	0·23	0·27	0·19	0·22	0·03	B > rest; A > C						
Exchangeable Ca (m.e. per 100 g.) . . .	0–6	4·0	4·4	5·7	4·7	0·8	C > others	3·3	2·5	3·3	2·5	0·7	A & C > B & D	1·81	1·71	1·72	1·51	0·16	Others > D
	6–12	2·7	2·9	4·4	3·3	0·7	C > others	3·0	2·2	2·6	2·4	0·6	A > B						
Exchangeable Mg (m.e. per 100 g.) . . .	0–6	1·02	0·94	1·00	0·67	0·21	Others > D	Not available						0·52	0·52	0·54	0·49	0·05	C > D
	6–12	0·52	0·65	0·55	0·44	0·20	C > D												

For analytical methods see References [5] and [6]. pH was determined colorimetrically, carbon by Walkley-Black method, nitrogen by Kjeldahl, exchangeable cations by ammonium acetate leaching, potassium and calcium by flame photometer, and magnesium colorimetrically using Titan Yellow.

TABLE 8. *Mean Effects of 3–7 Years' Continuous Cropping on Soil Analyses*

Soil analysis	*Soil horizon (in.)*	KWADASO			NYANKPALA		
		Original value	*Effect of cropping*	*L.S.D. ($P = 0.05$)*	*Original value*	*Effect of cropping*	*L.S.D. ($P = 0.05$)*
Acid-soluble+ adsorbed(p.p.m.)	0–6	7·7	−4·2	2·7	2·0	+0·3	0·8
	6–12	3·3	−2·3	2·0	Not available		
Organic C (%)	0–6	1·98	−0·31	0·90	0·41	−0·10	0·10
Nitrogen (p.p.thou.)	0–6	1·57	−0·36	0·49	0·34	−0·02	0·05
Exchangeable K (m.e. %)	0–6	0·48	−0·37	0·24	0·18	+0·05	0·12
	6–12	0·41	−0·35	0·24	Not available		
Exchangeable Ca (m.e. %)	0–6	5·5	−0·2	2·9	1·8	−0·3	0·4

N.B. (1) Values for acid-soluble+adsorbed phosphorus have been corrected to allow for the effect of superphosphate treatments. No such corrections have been applied to other analyses as they were not significantly affected by fertilizer treatments.
(2) Values for pH and for the Ejura site are not available.

TABLE 9. *Acid-soluble+Adsorbed Phosphorus in Soil with the different Superphosphate Treatments*

Site	*Soil horizon (in.)*	*Acid-sol.+ads. phosphorus, in p.p.m.*				*No. of block replicns.*
		Without super-phosphate	*With P_1 treatment*	*With P_2 treatment*	*L.S.D. ($P = 0.05$)*	
Kwadaso	0–6	4·6	5·5	6·8	1·4	7
	6–12	1·8	2·2	2·3	0·4	6
Ejura	0–6	3·1	3·2	4·5	0·9	3
	6–12	1·8	1·9	2·4	0·4	3
Nyankpala	0–6	1·9	2·5	3·6	0·7	4

N.B. Fertilizer treatments had no other significant effects on soil analyses.

continuously cropped plots are averaged over the whole period since the start of the experiment in 1951, the small significant groundnut responses shown in Table 4 are obtained. A similar summation of cassava responses over the full 7 years shows them to be non-significant.

Under continuous cropping the yields of maize and groundnuts remained fairly steady, but cassava yields decreased with time, as shown in Table 5. This almost certainly indicates developing potassium deficiency, for other experiments at Kwadaso have shown that cassava responds strikingly to potassium fertilizers after about 4 years' continuous cropping. Maize responses to superphosphate on the continuously cropped plots were also found to be significantly correlated with years; in this case the trend was of increasing response with increasing years, i.e. a progressive shortage of available soil phosphorus.

Soil analyses confirm some of the above results. Thus from Table 7 it will be seen that the outstanding effect of the grass fallows at Kwadaso was to maintain the level of exchangeable potassium at about twice that

in continuously cropped plots, and that rotation B which had the highest test-crop yields also had the most exchangeable potassium in the soil. Exchangeable magnesium, pH, and acid-soluble+adsorbed phosphorus were all greater after fallowing, although the differences in phosphorus level were not significant; but the figures for organic carbon, nitrogen, exchange capacity, and exchangeable calcium do not clearly separate the unrested from the rested rotations, although they are significantly higher for rotation C than for the others. Table 8 shows that the two significant effects of continuous cropping on soil composition have been to lower its acid-soluble+adsorbed phosphorus and exchangeable potassium contents. These last figures are not very conclusive evidence by themselves, as the soil samples taken at the start of the trial had been kept air dry for 3 to 7 years before being analysed, and changes in these constituents might have taken place during that time; but they are nevertheless in accordance with the other results quoted above and support the picture of severe potassium deficiency and less intense phosphorus deficiency developing in the Kwadaso soils under continuous cropping.

The only significant effect of fertilizers shown by these soil determinations was that superphosphate raised the content of acid-soluble+adsorbed phosphorus (Table 9).

Ejura Experiment

The cropping sequence was the same as at Kwadaso. The grass sown was a mixture of *Andropogon gayanus* and *Pennisetum polystachyon* which usually gave a fallow consisting mainly of the Andropogon and *Imperata cylindrica*, a common and persistent weed in this area. Grass top-growth was much less heavy than at Kwadaso (see Table 6).

The mean yields of each test crop for each rotation are given in Table 1, which shows that: (i) first-year maize yields after 1 or 2 years' rest were highly significantly less than after 3 years or no rest; (ii) groundnut yields after 2 or 3 years' rest were highly significantly greater than after 1 year or no rest; (iii) second-year maize yields after 3 years' rest were highly significantly greater than those of other rotations. It appears, therefore, that grass rests reduced the yields of the maize crop which immediately followed them, but that later crops had higher yields the longer the rest period. An explanation of this behaviour is given below when considering the interaction between fertilizers and the rotations.

The interactions between rotations and trial years were highly significant with all the test crops. Figs. 1, 2, and 3 show that no crop had its yields improved by the fallows when the blocks started to come under test in 1953–4; later the fallows were beneficial, and in 1957 the yields of each crop decreased in the order A B C D with the one exception that rotation D slightly outyielded C with first-year maize. It is clear, therefore, firstly that resting the land under grass became increasingly beneficial with time and secondly that it was of less benefit to the first-test crops of maize than to succeeding ones.

The effects of the fertilizers on the crops are given in Table 2. Groundnuts did not respond significantly, but the maize responses are interesting. First-year maize responded strikingly to ammonium

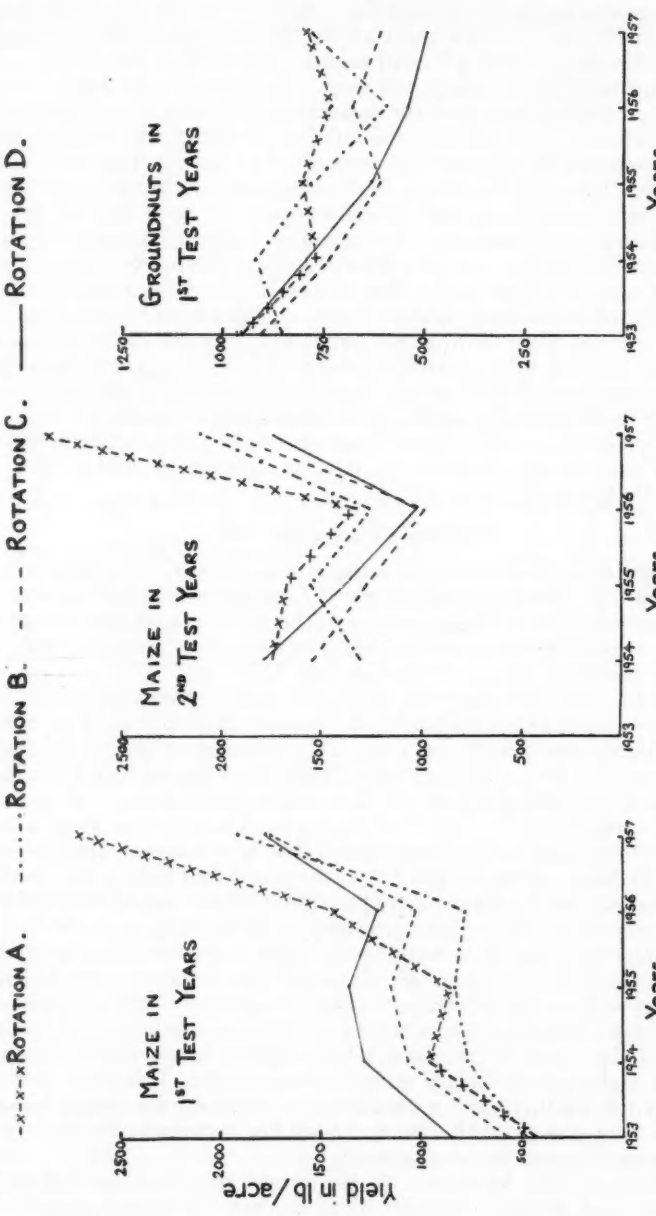

Fig. 1

Fig. 2

Fig. 3

Graphs showing annual yields of test crops in rotations at Ejura.

sulphate but not to superphosphate, while second-year maize responded less to ammonium sulphate and considerably to superphosphate; interactions between the effects of the two fertilizers were insignificant and usually positive (so providing no evidence of sulphur deficiency). As shown in Table 3 the interaction between ammonium sulphate and rotations with the first-test-year maize was significant and indicates that at Ejura grass rests caused the succeeding maize to be short of nitrogen. The corresponding superphosphate interactions with rotations were not significant, but for both crops of maize the responses to superphosphate were greatest on the continuously cropped plots and least after 2 or 3 years' rest; this suggests that the grass fallows rendered phosphorus available to crops in the succeeding years. The low yields of maize immediately after the grass fallows seem therefore to have been mainly due to nitrogen deficiency; while the high yields of the second-year maize were probably caused by phosphorus made available by the fallows, accompanied by a much-reduced nitrogen deficiency.

The effects of fertilizers on the crops did not vary significantly from year to year, but the interaction between superphosphate and years was significant for maize on the continuously cropped plots and showed a non-significant trend of progressively increasing response which may reflect a growing shortage of available phosphorus in the soil. But it must be remembered that maize in the earlier years was more affected by attacks of rust.

Three other results from analysis of the yield figures for the continuously cropped plots must be noted. Averaged over all the 7 years of the experiment, groundnuts responded positively to superphosphate and negatively to ammonium sulphate (see Table 4). Secondly, cassava yields did not fall off with time as they did at Kwadaso; instead the yields show a steep rise to a maximum in 1953–4 which was probably primarily due to better supervision on the Station. Thirdly, although the direct effects of ammonium sulphate and superphosphate did not significantly affect cassava yields, their interaction was highly significantly positive, N_2P_2 being +960 lb./acre.

Table 7 shows that soil which had been rested for 3 years, and to a lesser extent that rested for shorter periods, had, as compared with continuously cropped soil, higher contents of acid-soluble+adsorbed phosphorus, organic carbon, nitrogen, and exchangeable cations. No one of these appears especially outstanding, rather the effect of the fallows seems to be a general improvement in soil fertility.

Nyankpala Experiment

As at Ejura the grass rest was intended to be under a mixture of *Andropogon gayanus* and *Pennisetum polystachyon*, but usually the resting plots were dominated by *Pennisetum pedicellatum*, a grass which closely resembles *P. polystachyon* and is equally common locally, and by the Andropogon on longer-growing plots. During the dry seasons of 1954–5 and 1956–7, and probably at least once before 1952, fire swept through the experiment, so that 3 years' uninterrupted growth of grass were rarely if ever attained during the 3-year rest periods; the mineral

nutrients in the grass would not, however, have been lost but returned to the plots in the ash. These fires may partly account for the low weights of grass cut on the rested plots before test cropping (see Table 6).

Unlike Kwadaso and Ejura, Nyankpala has only one rainy season and the cropping sequence in this experiment was:

Year 1	*Year 2*	*Year 3*	*Year 4 (1st test year)*	*Year 5 (2nd test year)*
A. Grass	Grass	Grass	Maize	Guinea corn
B. Groundnut	,,	,,	,,	,,
C. ,,	Maize	,,	,,	,,
D. ,,	,,	Guinea corn	,,	,,

The only significant difference between the effects of the rotations on the test crops was that maize on the continuously cropped plots yielded better than on rested plots (see Table 1). This difference varied significantly from year to year but no clear trend is discernible. There were no significant interactions between rotations and fertilizer treatments, with the single exception that the response of first-test-year maize to ammonium sulphate was least after no rest (see Table 3). It seems, therefore, that in the first 5-year cycle of the experiment grass fallows have not benefited the crops and their main effect has been to produce a temporary shortage of available nitrogen.

The effects of the fertilizers on the test crops are given in Table 2. Ammonium sulphate, superphosphate, and the interaction between them highly significantly increased maize and guinea corn yields; the higher rate of ammonium sulphate gave appreciably higher yields than the lower rate, whereas the two levels of superphosphate had more nearly equal effects. The effects of both fertilizers on both crops tended to increase with time although in no case was the trend significant—probably because the 5-year period was too short. The same trends were, however, shown on the continuously cropped plots over the full 9 years of the trial and were in this case significant (see Table 5). Without ammonium sulphate or without superphosphate yields of maize decreased with the years of cropping, and responses to the fertilizers correspondingly increased; whilst where both fertilizers were regularly applied there was no significant decline in yields. Guinea corn without fertilizers showed the same decline and with fertilizers the same maintenance of yields as the maize, but its fertilizer responses did not significantly increase. Groundnuts showed none of these trends, although the interaction of its superphosphate responses with years was significant.

From Table 7 it is seen that the grass rests seem to have increased the organic carbon, cation-exchange capacity, and exchangeable calcium and magnesium of the soil. But they did not improve the content of acid-soluble+adsorbed phosphorus and, although no satisfactory correlation has been established in Ghana between this estimate of available soil phosphorus and crop responses to phosphatic fertilizers, this implies that the fallows have not rendered phosphorus readily available to succeeding crops. If that is so it is not surprising that grass fallows have

not benefited the crops on these phosphorus-deficient soils. Continuous cropping decreased the already small organic matter content of the soil (see Table 8), but was not found to produce any other significant effect. If the loss of organic matter is the main cause of the increasing nitrogen and phosphate deficiencies mentioned above, the grass fallows would have been expected to be more effective than they have been; perhaps only stands of grass better than those grown on the trial can appreciably raise or maintain the phosphorus status of the soil.

Table 9 shows that the superphosphate treatments nearly doubled the soil content of acid-soluble+adsorbed phosphorus, and once again emphasizes the severity of the phosphorus deficiency in the soil.

Discussion and Provisional Conclusions

In this first 5-year cycle of the experiments the total yields from continuous cropping have been greatest because the increases following the resting periods have nowhere made up for the absence of years of cropping. But it is, of course, much too early to decide which of the four rotations is to be preferred economically, and it is clear that the fertility of continuously cropped plots has already declined seriously at Kwadaso and Nyankpala. The next 5-year cycle of these trials may well be crucial.

The grass rests have benefited succeeding crops on the forest soil of Kwadaso and on the savannah soil of Ejura, but not on the low-fertility soil of Nyankpala. So far the nature of the benefit seems to be adequately explained by chemical factors, the supply of potassium and phosphorus, and perhaps magnesium, being important at Kwadaso, and a general increase in nutrient status, especially that of phosphorus, being effected at Ejura. It seems likely that with the use of phosphatic and potassic fertilizers, perhaps supplemented with magnesium, the crop/fallow ratio in the rotation could be increased considerably above that normally practised by the peasant farmer; but the significant effect the fallows have usually had in raising the organic carbon content of soil suggests that a periodical rest will remain necessary unless organic manures are also applied.

There seems to be no reason for thinking fallows confer any important benefit by improving the structure of these sandy soils. Any improvement would appear to be very temporary and would not survive ridging, cultivation, and the heavy raindrop-impact of tropical storms, and no such improvement has been observed in the field. Nevertheless, some preliminary attempts have been made to compare the physical characteristics of plots in their first test years. As well as hand sieving (both wet and dry) and measurements of soil moisture content, two simple field tests were used. In one the rate at which water drained into the top soil was measured, using a metal cylinder with guard ring which was driven a few inches into the soil and filled to a fixed level with water; in the other, drops of water were directed from a fixed height on to a point on the soil surface which was surrounded by a cylinder of blotting-paper on which soil splash marks were recorded. None of these tests showed

any difference between the soil from different rotations which approached significance, and they were discontinued.

At Nyankpala nitrogen and phosphorus were the main crop requirements. The grass fallows in the trial have apparently done little if anything to supply them, and it seems that on this poor soil with occasional burning it is rare to get growth of grass which is good enough to increase the phosphorus status of the soil effectively. But, although cropping continuously with regular applications of ammonium sulphate and superphosphate has not yet resulted in a significant decline in yields, the fact that the organic-carbon content of the soil has been reduced by nearly one-quarter makes it unlikely that yields will long continue to be maintained by inorganic fertilizers alone. Fertilizers should perhaps be applied to the grass fallows as well as to the crops.

Finally, all the grass fallows tended to keep succeeding cereal crops short of nitrogen; this effect was significant in the savannah trials, but also seemed to be just noticeable at Kwadaso after the longest rest period. The use of grass as the fallow in the savannah would therefore seem to necessitate nitrogenous fertilizers if cereals were included early in the rotation, and it seems likely that in this zone, which is in any case rather short of nitrogen, a leguminous fallow would be preferable to grass; pigeon pea (*Cajanus cajan*) has proved promising.

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